FIG.1

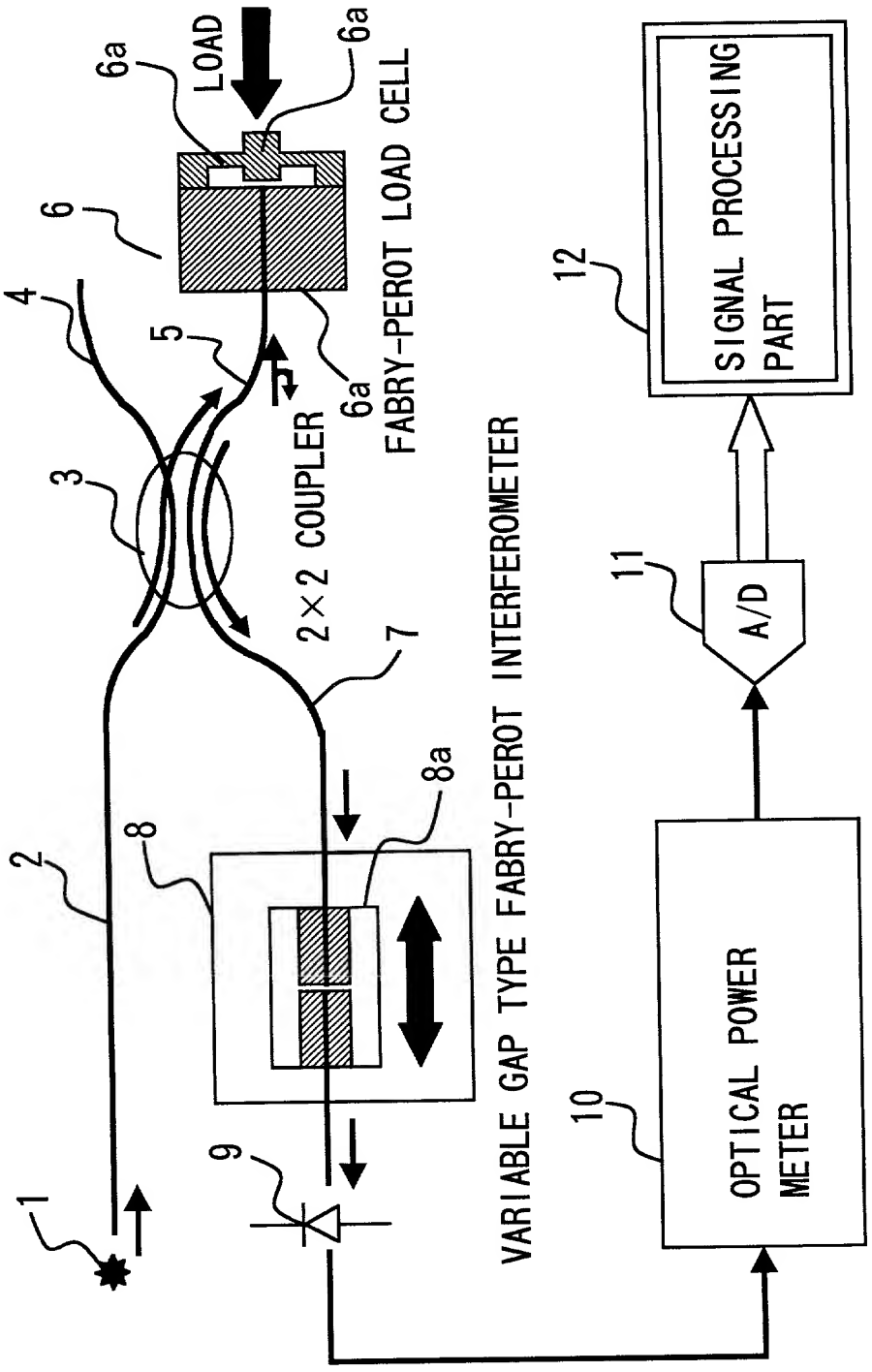

LOAD
6a
6a
6
4
5
3
2×2 COUPLER
6a
FABRY-PEROT LOAD CELL
7
8a
8
2
1
9
VARIABLE GAP TYPE FABRY-PEROT INTERFEROMETER
10
OPTICAL POWER METER
11
A/D
12
SIGNAL PROCESSING PART

FIG.2

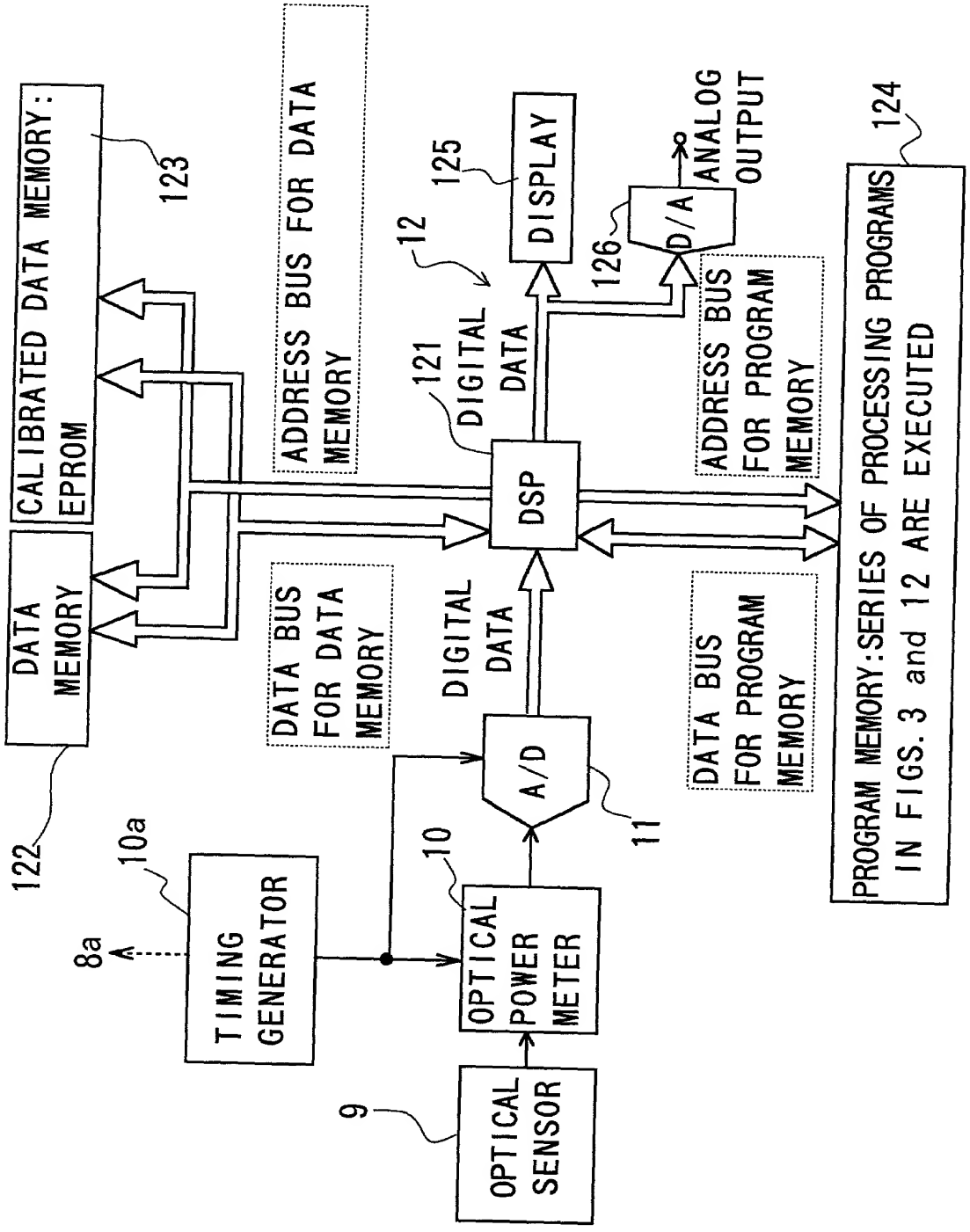

CALIBRATED DATA MEMORY: EPROM
123
ADDRESS BUS FOR DATA MEMORY
12
125
DISPLAY
121
DIGITAL DATA
126
D/A
ANALOG OUTPUT
ADDRESS BUS FOR PROGRAM MEMORY
DATA MEMORY
DSP
PROGRAM MEMORY: SERIES OF PROCESSING PROGRAMS IN FIGS. 3 and 12 ARE EXECUTED
124
DATA BUS FOR DATA MEMORY
DIGITAL DATA
DATA BUS FOR PROGRAM MEMORY
A/D
122
10a
10
11
8a
TIMING GENERATOR
OPTICAL POWER METER
9
OPTICAL SENSOR

FIG.3

OUTPUT OF TIME-SERIES SIGNAL
$S_{SIG}(n)$

↓

<S1> EXTRACTION OF OPTICAL CROSS-CORRELATION SIGNAL
$S_{SIG}(n) \Rightarrow S_{LCOR}(n)$

$S_{LCOR}(n) = S_{SIG}(n) - K \cdot S_{BACK}(n)$

↓

<S2> LPF PROCESSING
$S_{LCOR}(n) \Rightarrow S_{LCOR,\ LPF}(n)$

↓

<S3> DETECTION OF EITHER MINIMUM POSITION OR MAXIMUM POSITION

SMOOTHING DIFFERENTIAL
$S_{LCOR,\ LPF}(n) \Rightarrow dS_{LCOR,\ LPF}(n)/dn$

CALCULATION OF ZERO-POINT POSITION
$dS_{LCOR,\ LPF}(X)/dX = 0 \Rightarrow X_{PEAK}$

FIG. 4

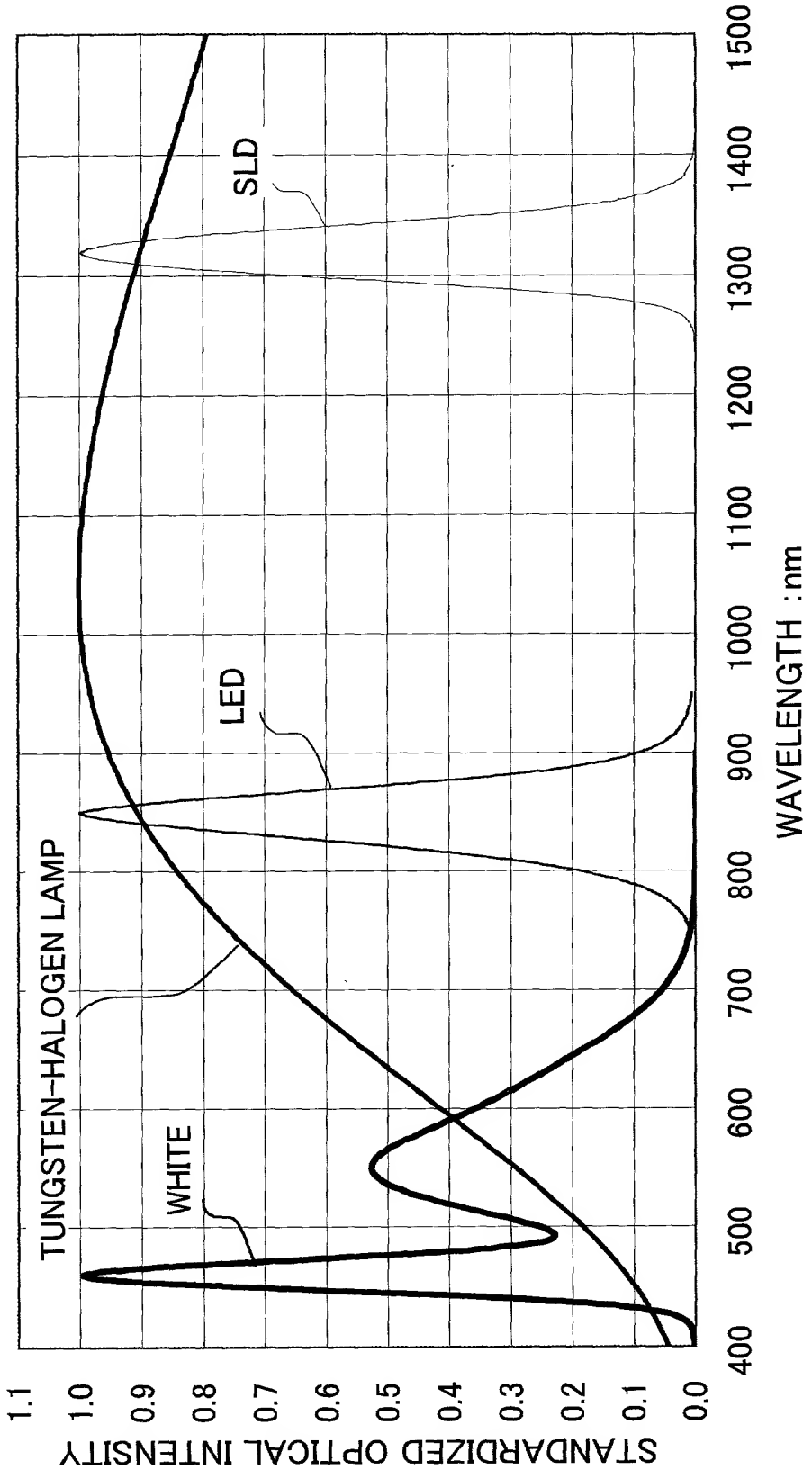

STANDARDIZED OPTICAL INTENSITY
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
WAVELENGTH : nm
TUNGSTEN-HALOGEN LAMP
WHITE
LED
SLD

FIG. 5A

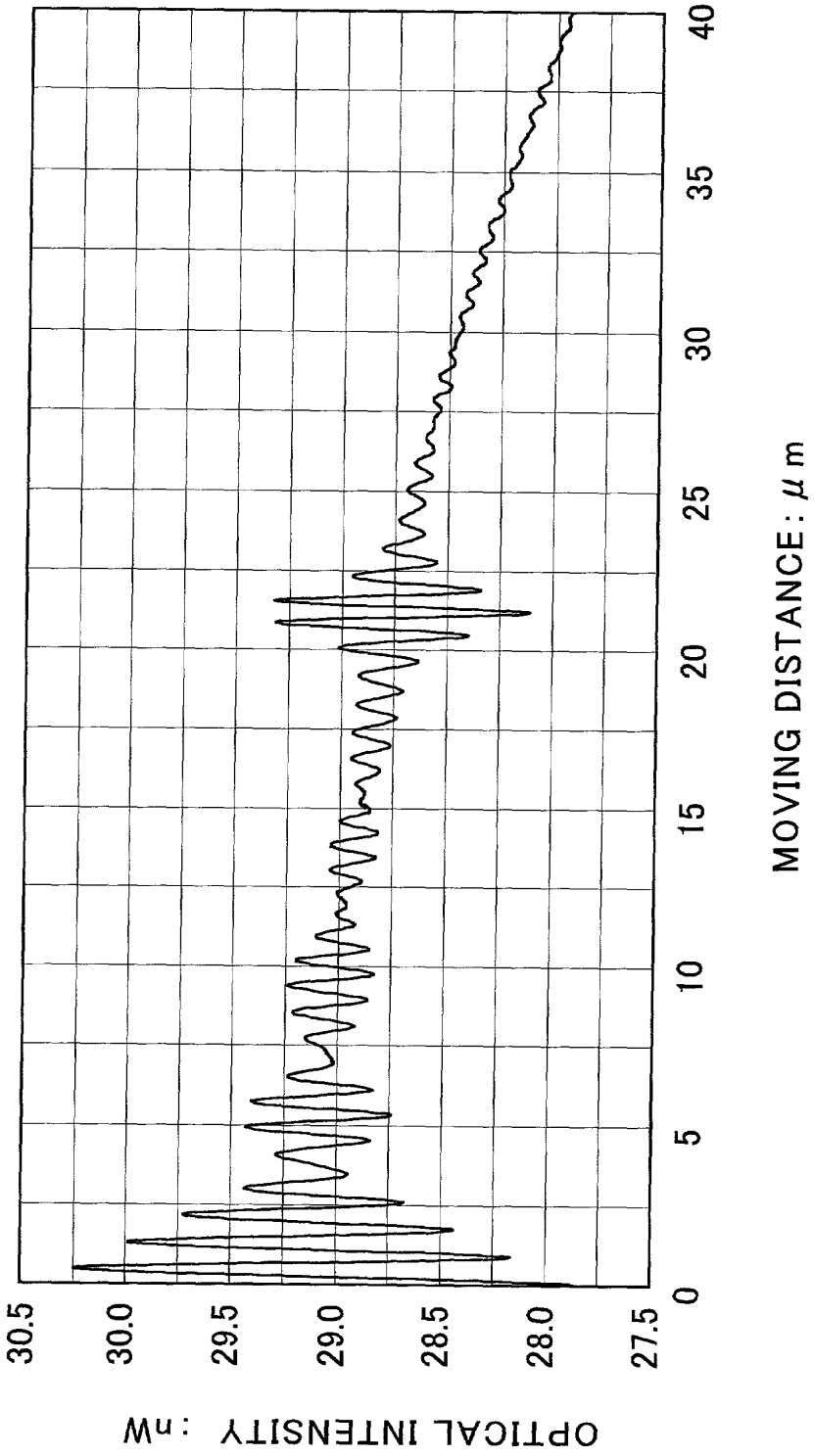


FIG. 5B

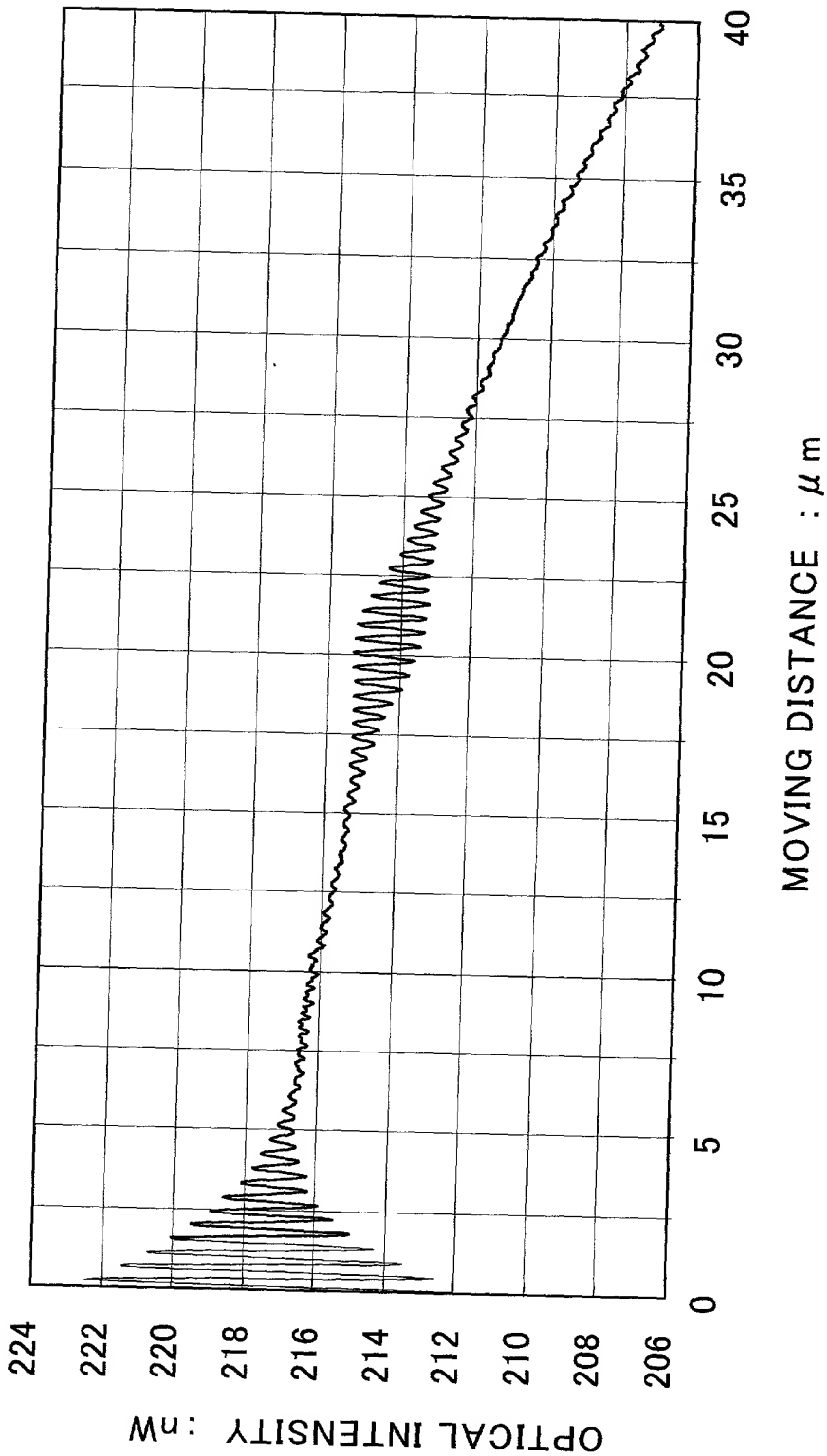

OPTICAL INTENSITY : nW
224
222
220
218
216
214
212
210
208
206
0
5
10
15
20
25
30
35
40
MOVING DISTANCE : μm

FIG. 5C

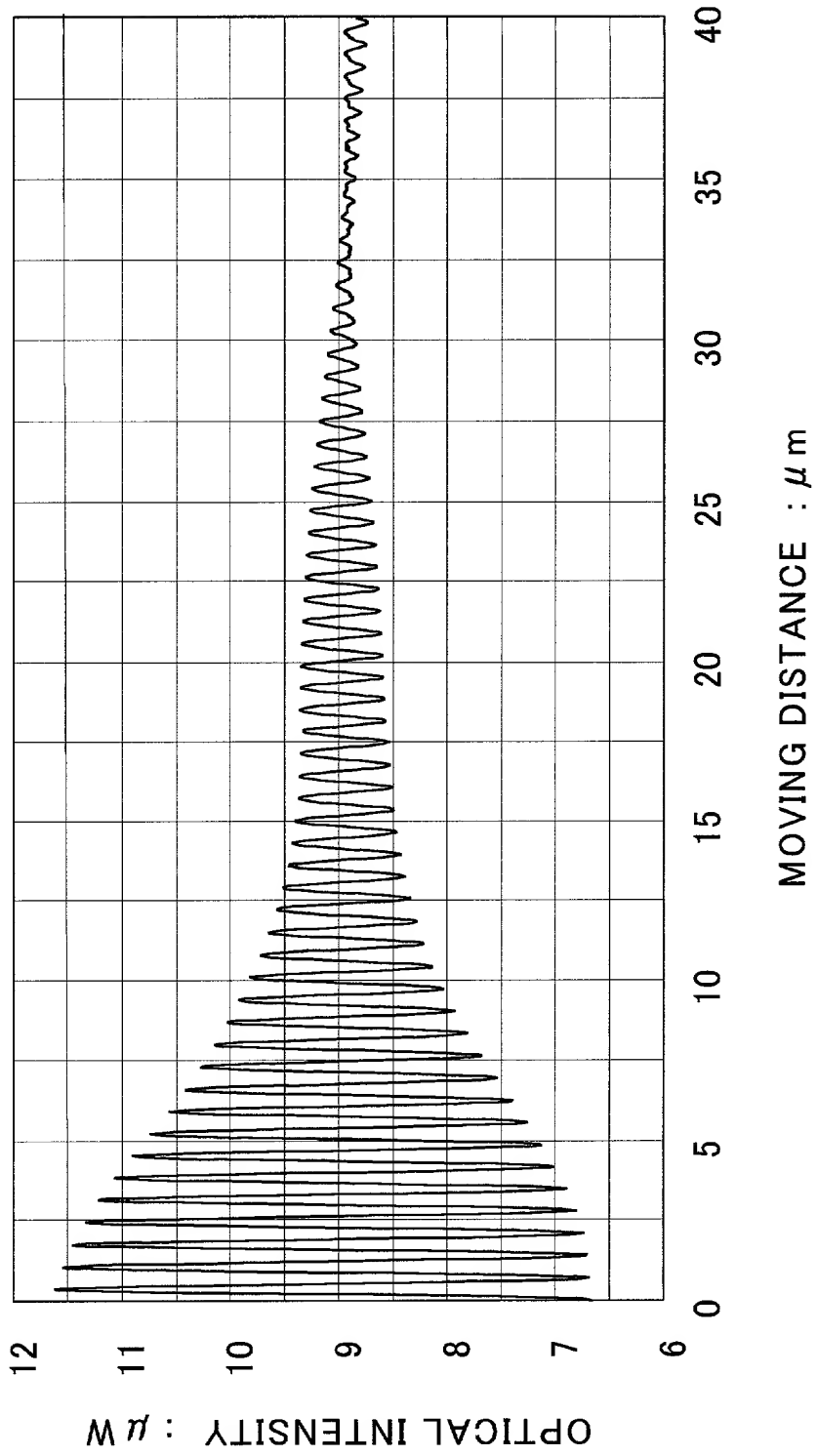

OPTICAL INTENSITY : μW
12
11
10
9
8
7
6
0
5
10
15
20
25
30
35
40
MOVING DISTANCE : μm

FIG. 6A

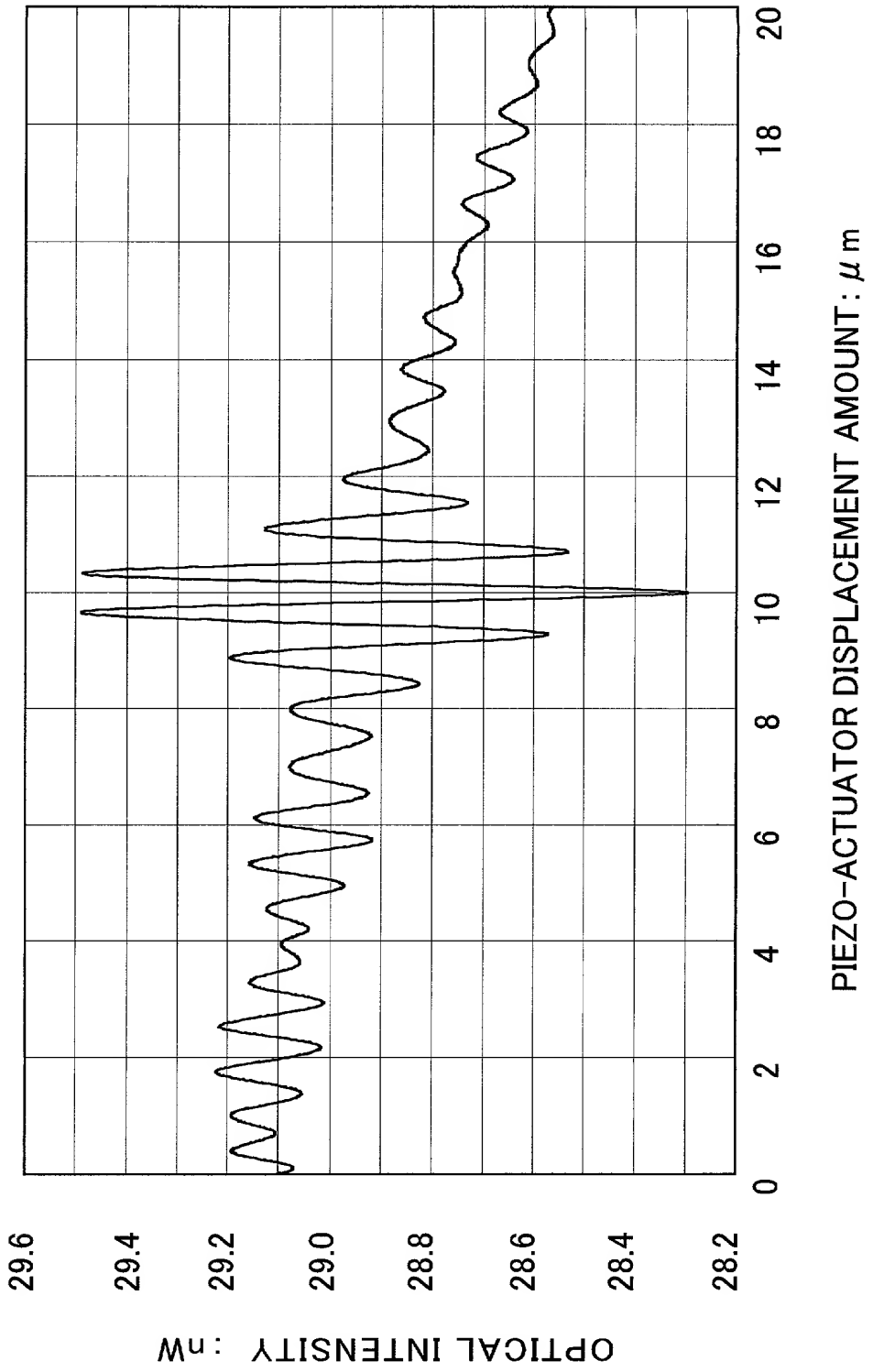

OPTICAL INTENSITY : nW
29.6
29.4
29.2
29.0
28.8
28.6
28.4
28.2
0
2
4
6
8
10
12
14
16
18
20
PIEZO-ACTUATOR DISPLACEMENT AMOUNT : μm

FIG. 6B

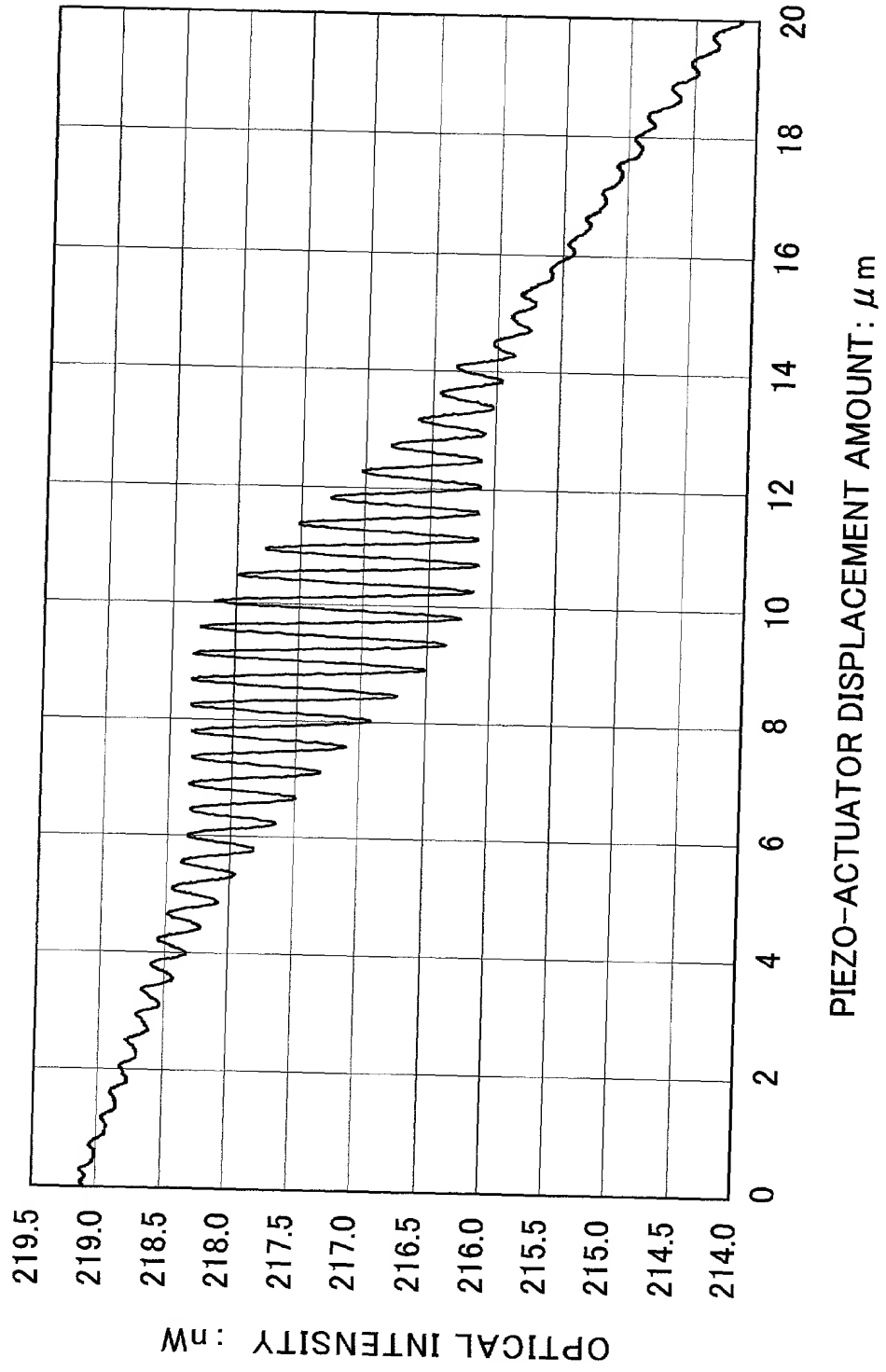

OPTICAL INTENSITY : nW
219.5
219.0
218.5
218.0
217.5
217.0
216.5
216.0
215.5
215.0
214.5
214.0
0
2
4
6
8
10
12
14
16
18
20
PIEZO-ACTUATOR DISPLACEMENT AMOUNT : μm

FIG. 6C

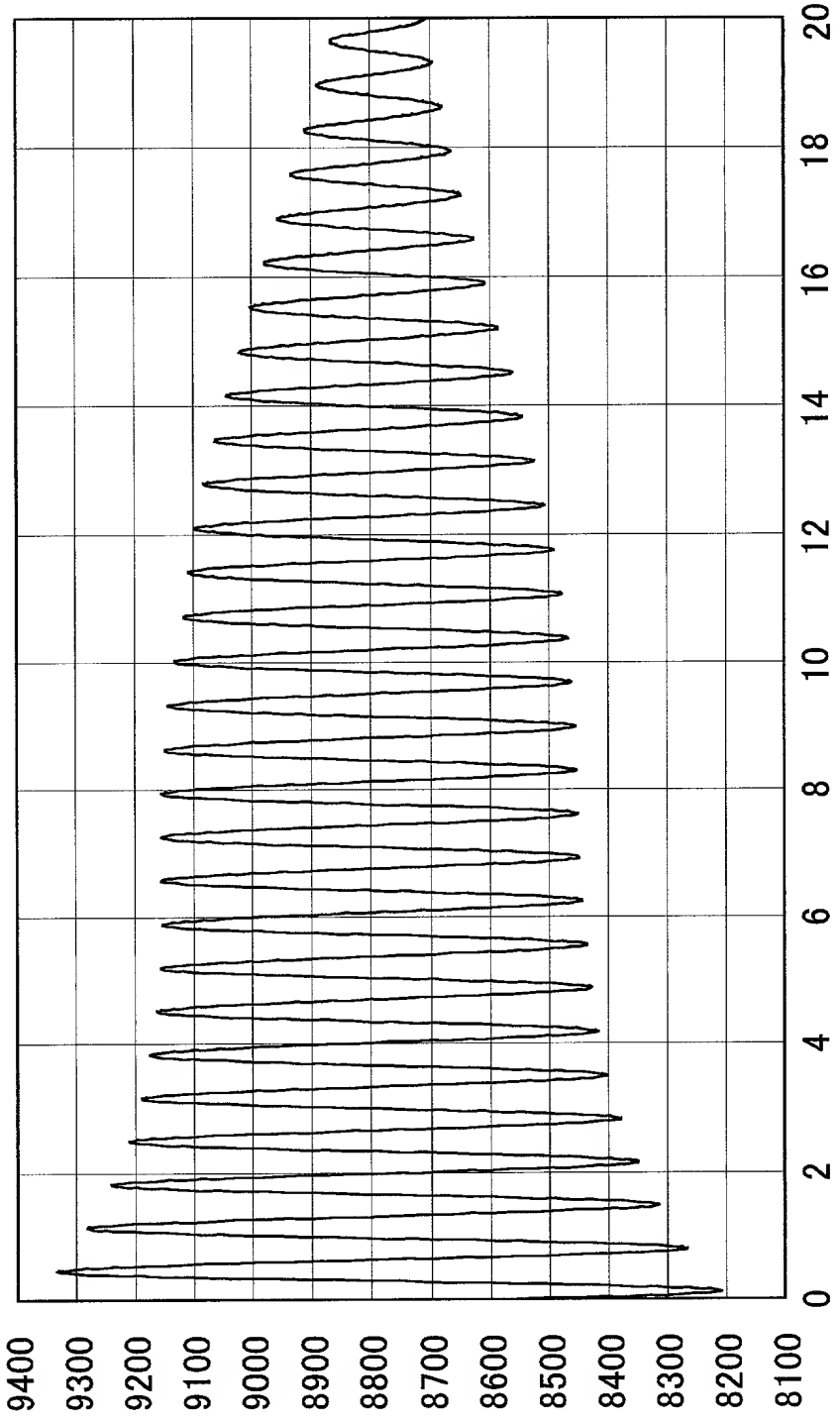

OPTICAL INTENSITY : nW
9400
9300
9200
9100
9000
8900
8800
8700
8600
8500
8400
8300
8200
8100
0
2
4
6
8
10
12
14
16
18
20
PIEZO-ACTUATOR DISPLACEMENT AMOUNT : μm

FIG. 7A

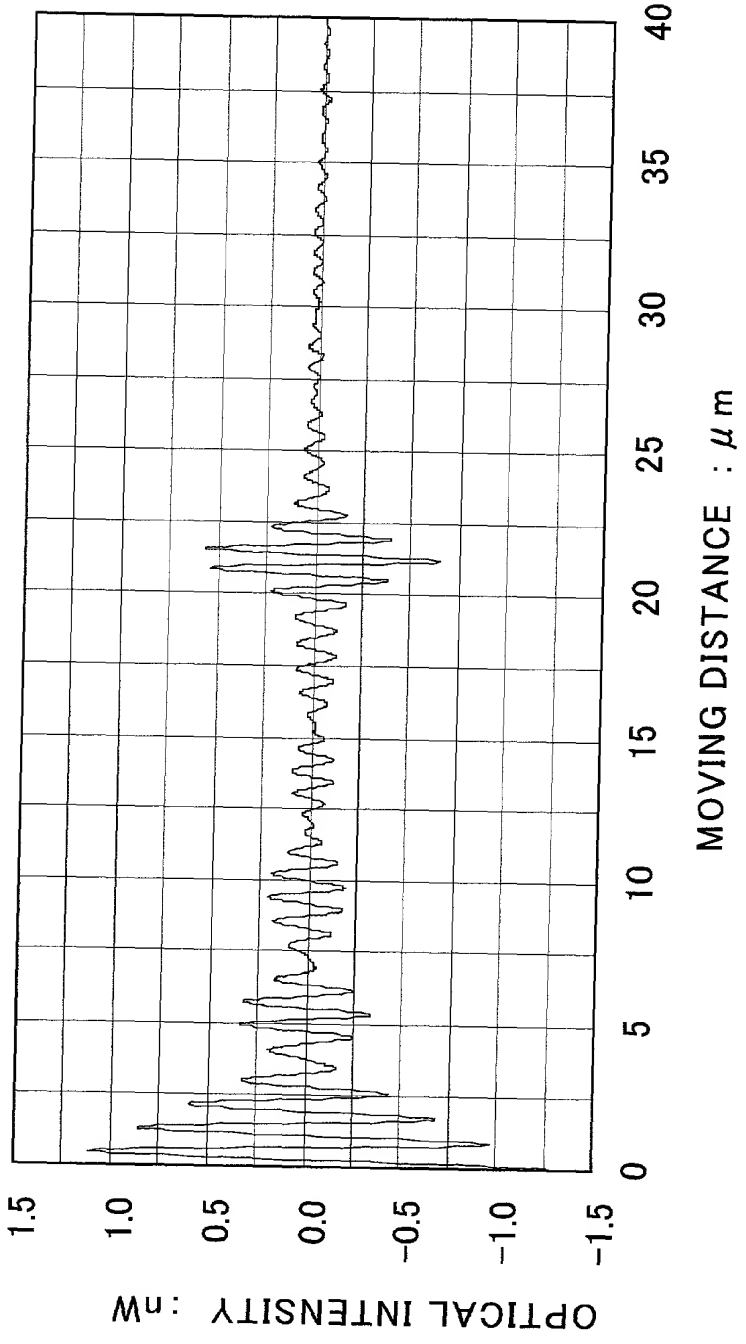

OPTICAL INTENSITY : nW
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0
5
10
15
20
25
30
35
40
MOVING DISTANCE : μm

FIG. 7B

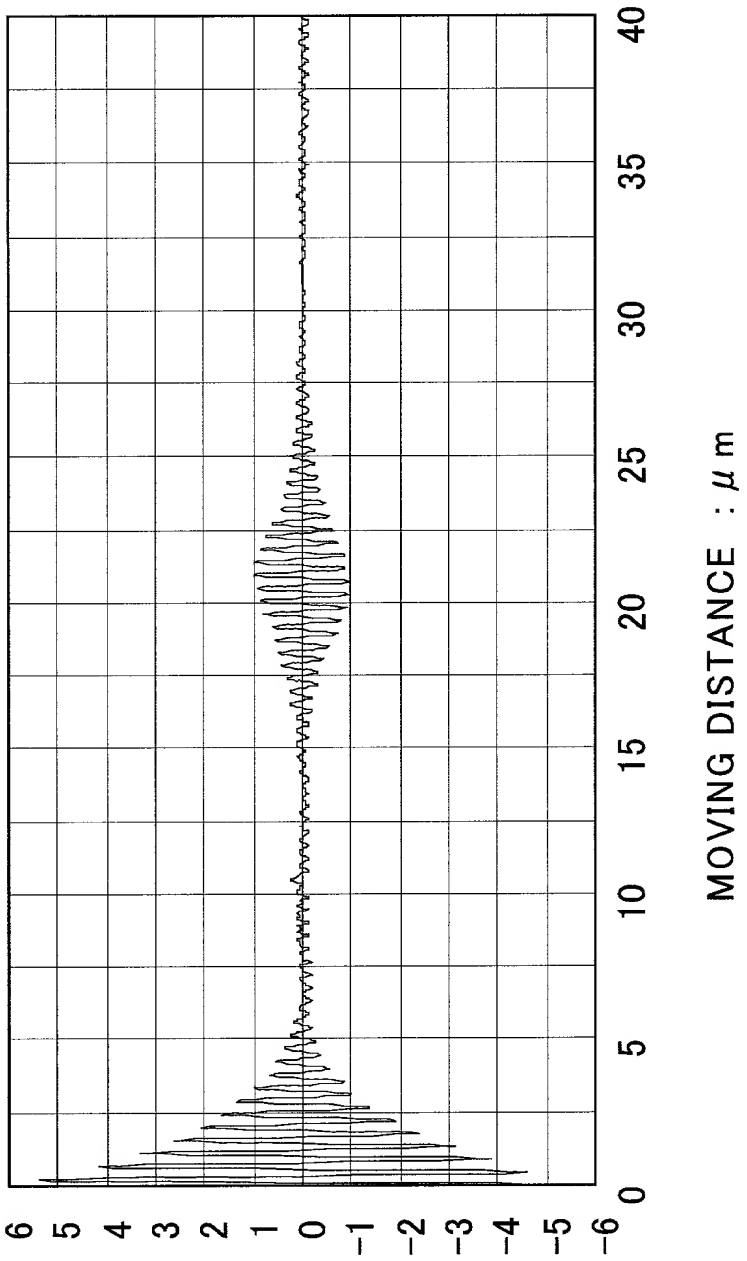

OPTICAL INTENSITY : nW
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
5
10
15
20
25
30
35
40
MOVING DISTANCE : μm

FIG. 7C

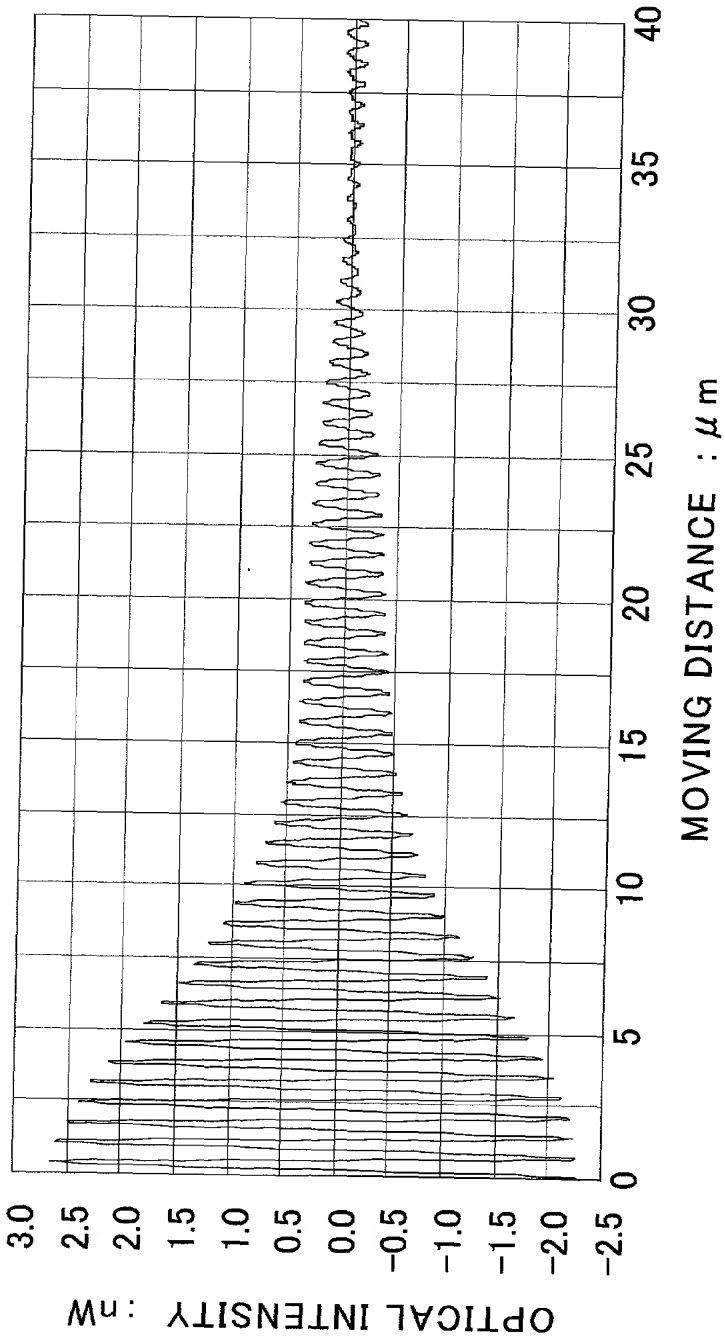

OPTICAL INTENSITY : nW
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
0
5
10
15
20
25
30
35
40
MOVING DISTANCE : μm

FIG. 8A

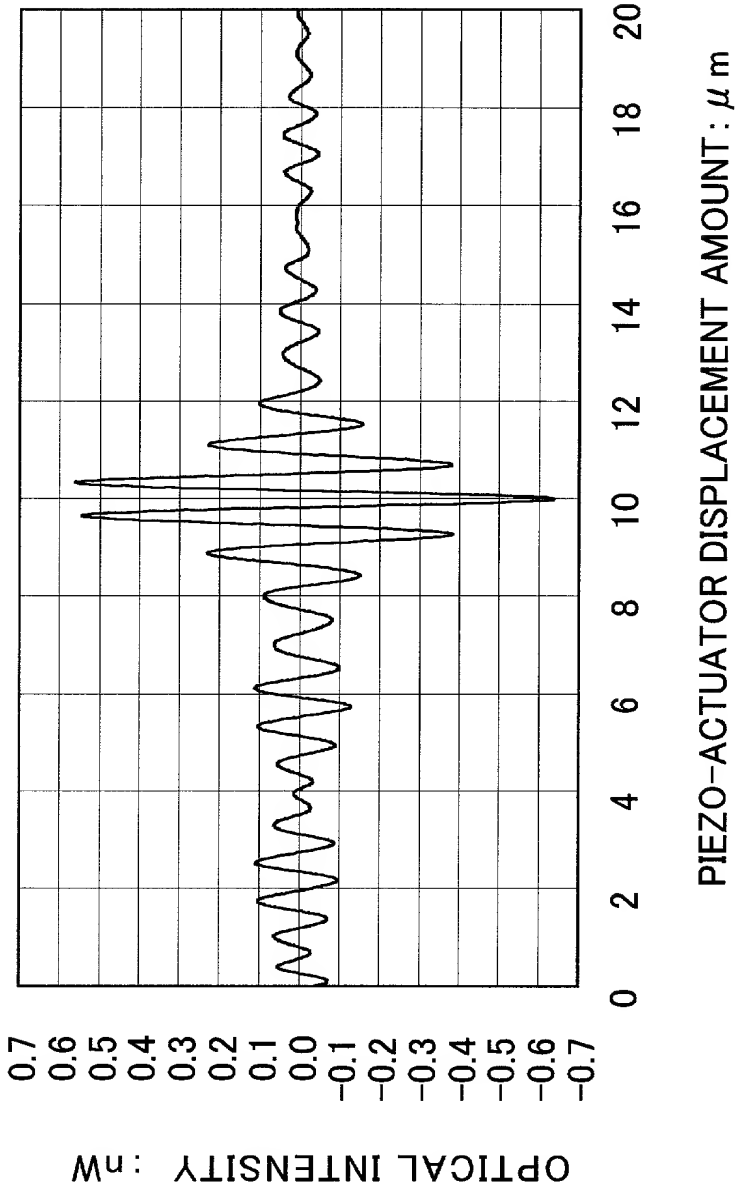

OPTICAL INTENSITY : nW
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
−0.6
−0.7
0
2
4
6
8
10
12
14
16
18
20
PIEZO-ACTUATOR DISPLACEMENT AMOUNT : μm

FIG. 8B

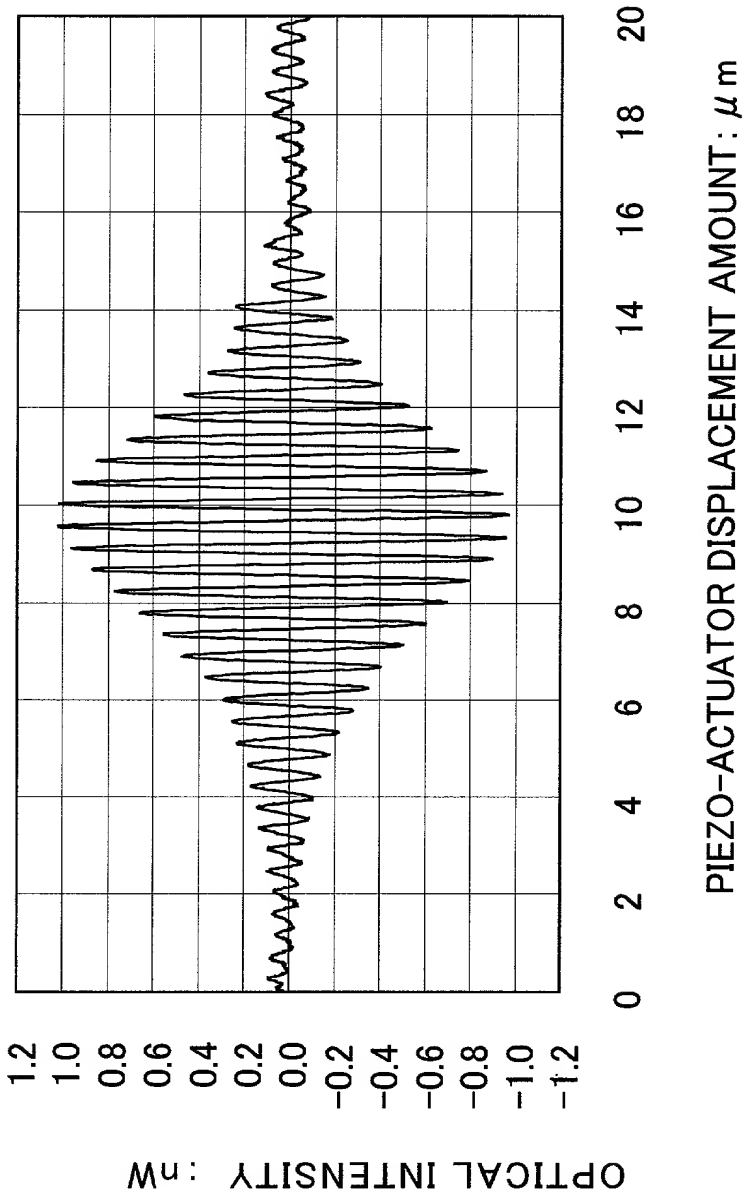


FIG. 8C

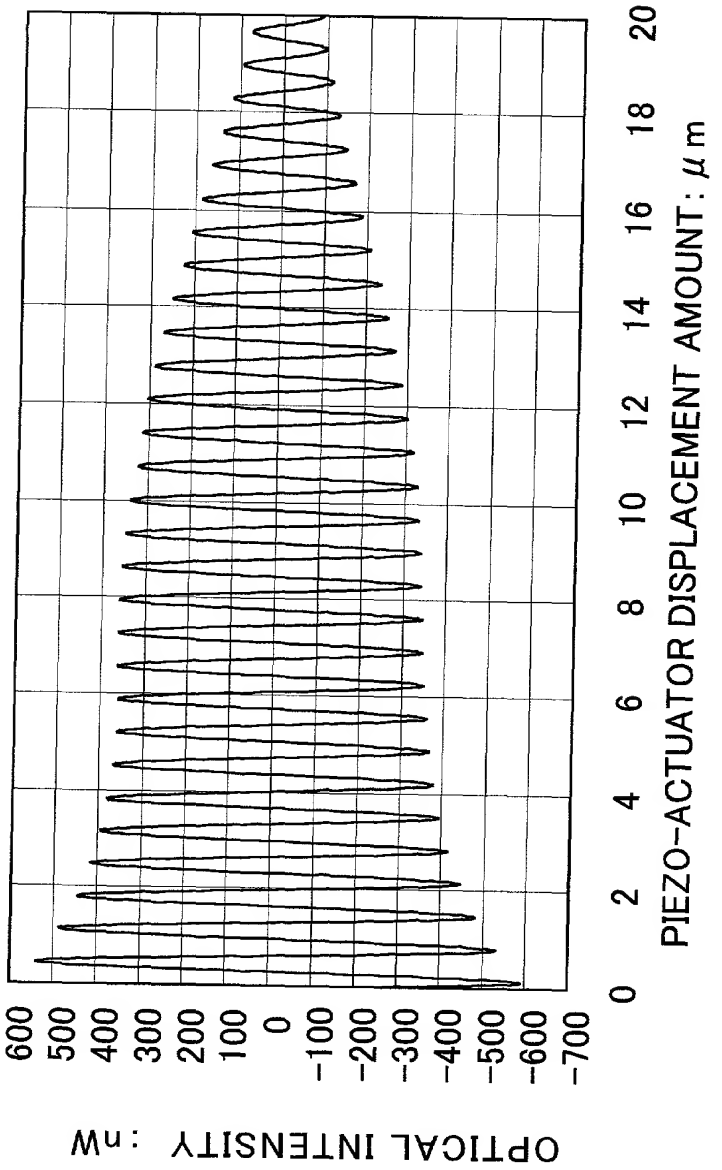

OPTICAL INTENSITY : nW
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
0
2
4
6
8
10
12
14
16
18
20
PIEZO-ACTUATOR DISPLACEMENT AMOUNT : μm

FIG. 9A

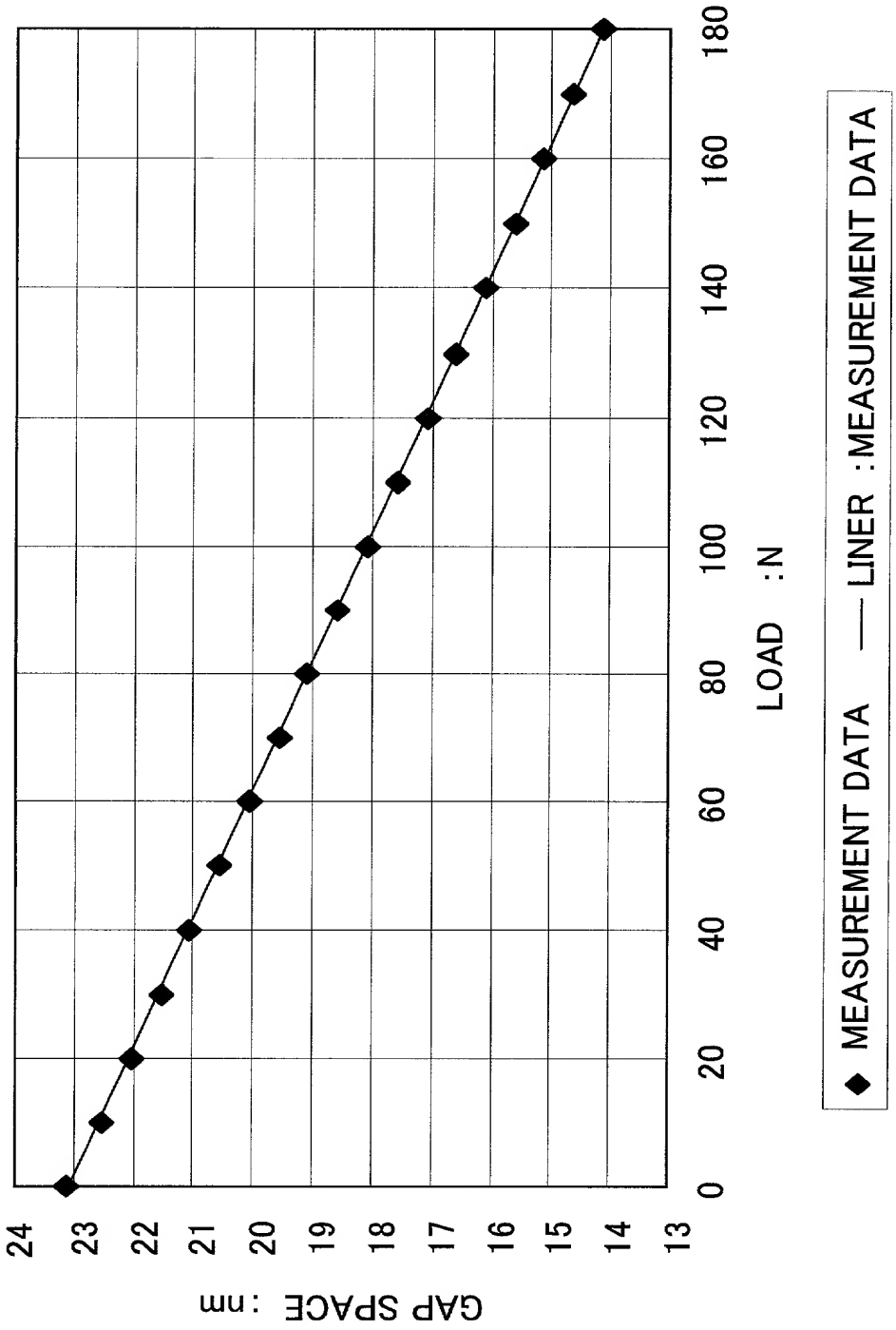

GAP SPACE :nm
24
23
22
21
20
19
18
17
16
15
14
13
0
20
40
60
80
100
120
140
160
180
LOAD :N
◆ MEASUREMENT DATA —— LINER :MEASUREMENT DATA

FIG. 9B

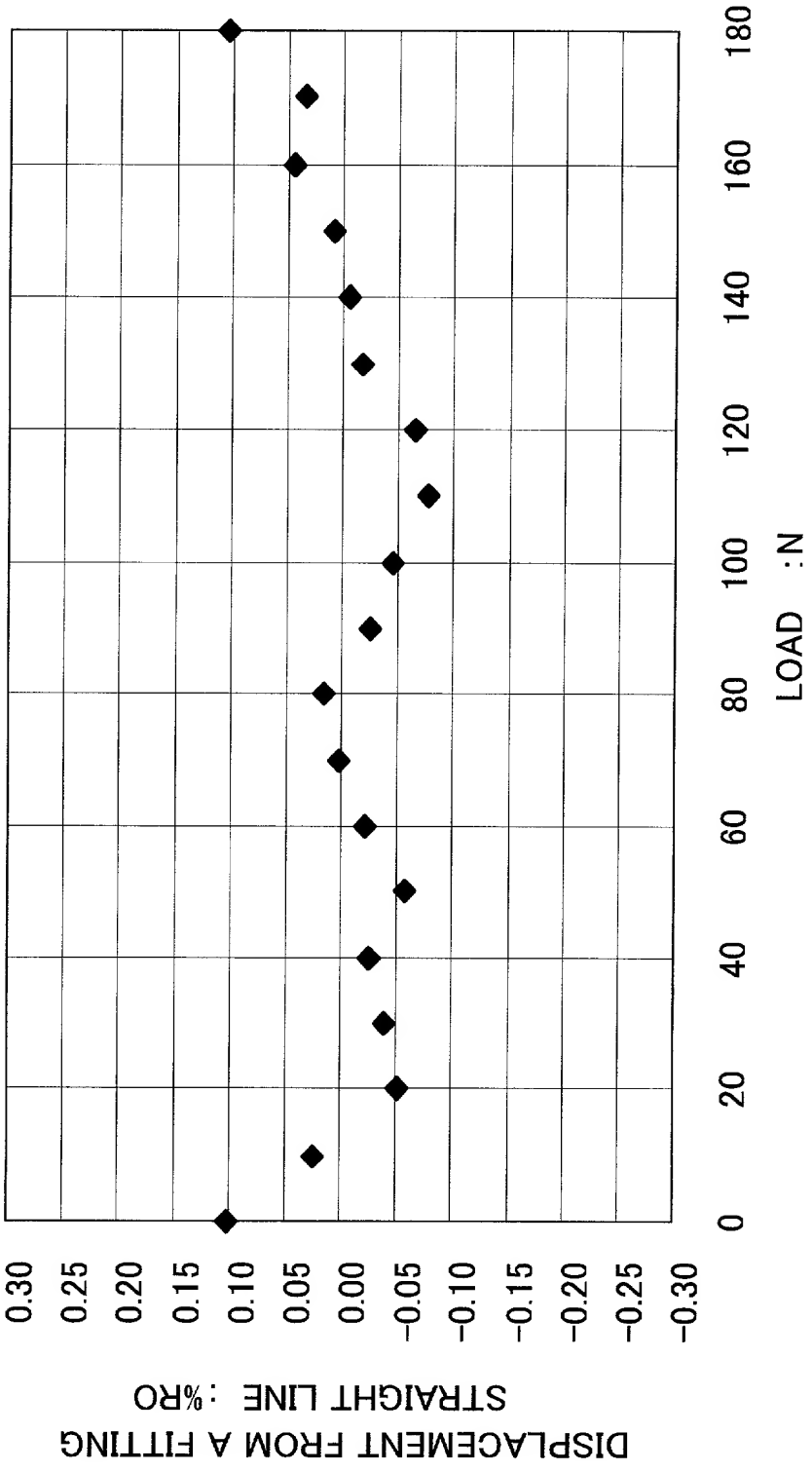

DISPLACEMENT FROM A FITTING STRAIGHT LINE :%RO
0.30
0.25
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
−0.25
−0.30
0
20
40
60
80
100
120
140
160
180
LOAD :N

FIG. 10

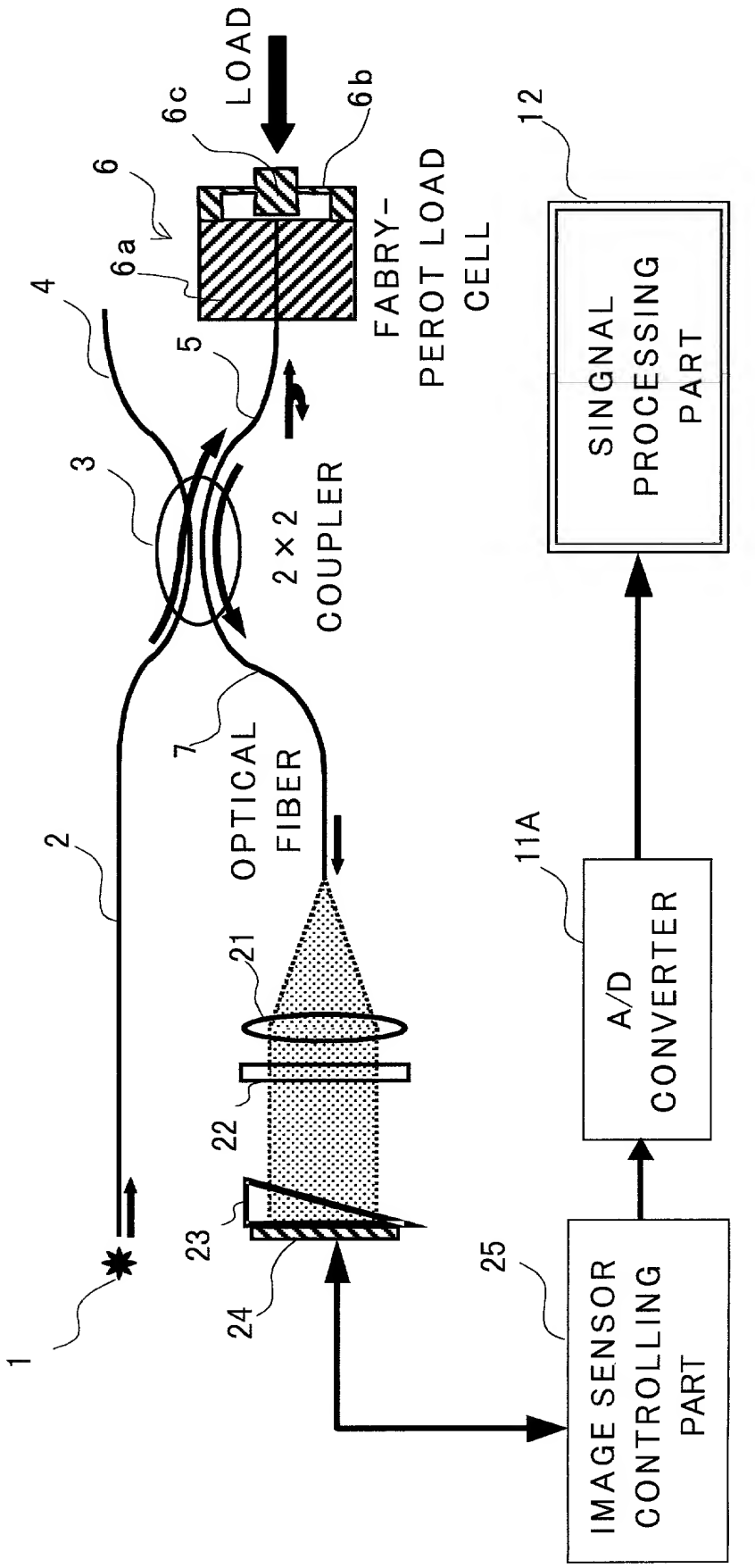

LOAD
6c
6b
6
6a
4
5
3
2 × 2 COUPLER
FABRY-PEROT LOAD CELL
12
SINGNAL PROCESSING PART
7
OPTICAL FIBER
2
11A
A/D CONVERTER
21
22
23
24
25
1
IMAGE SENSOR CONTROLLING PART

FIG. 11

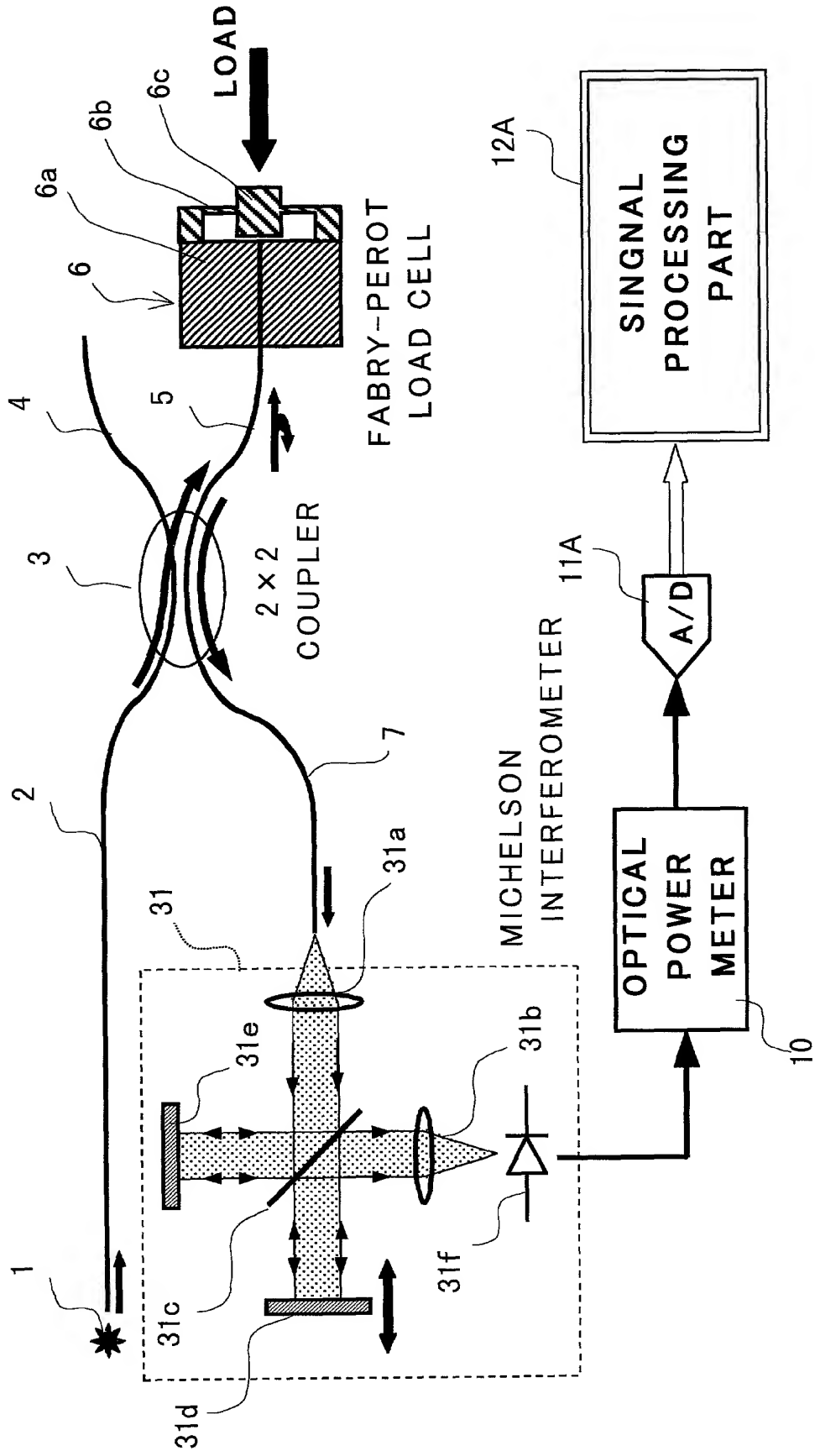

LOAD
6c
6b
6a
6
FABRY-PEROT LOAD CELL
12A
SINGNAL PROCESSING PART
4
5
3
2 × 2 COUPLER
11A
A/D
2
7
MICHELSON INTERFEROMETER
31a
31
OPTICAL POWER METER
10
31e
31b
1
31c
31f
31d

FIG.12

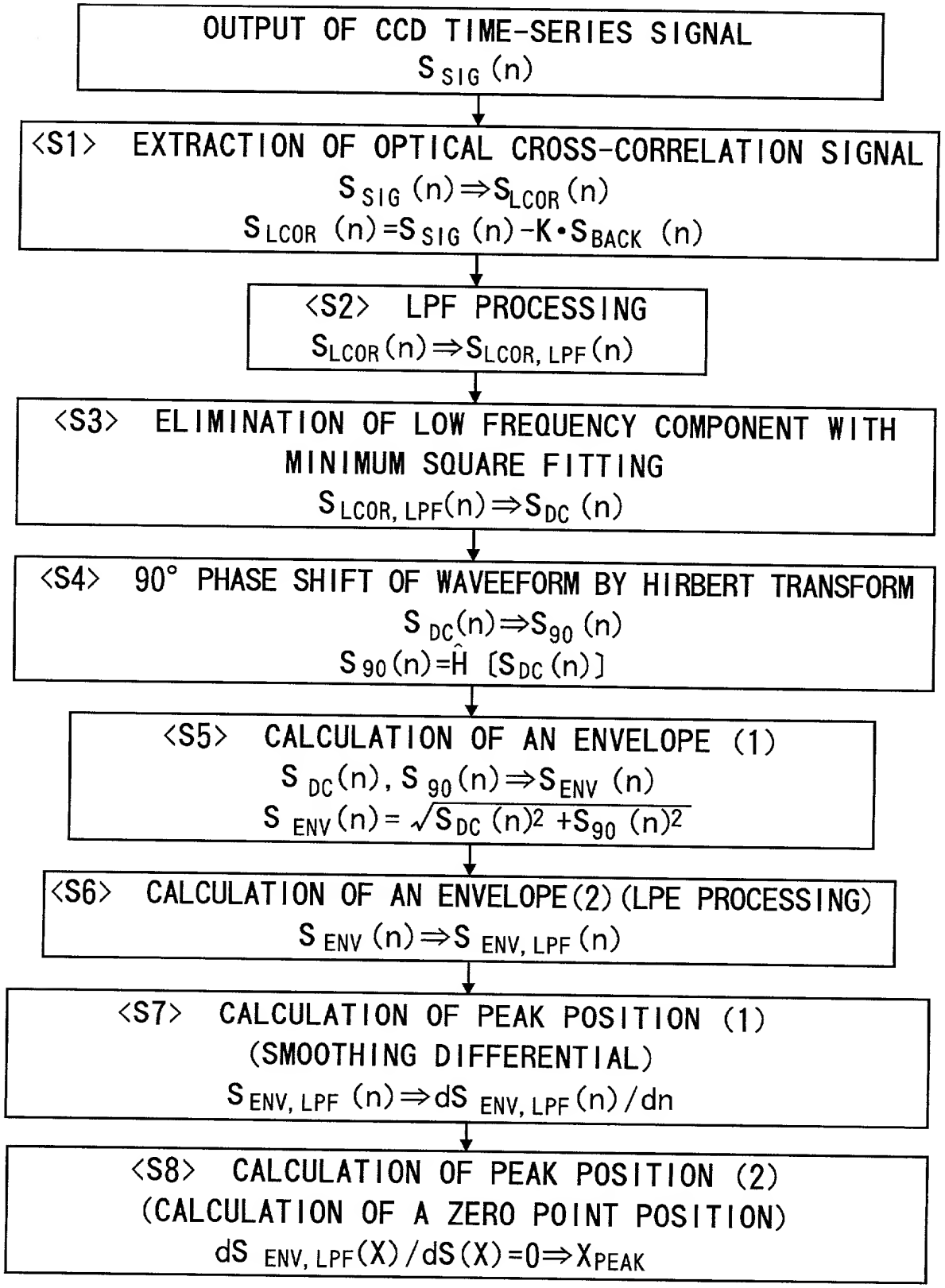


FIG.13

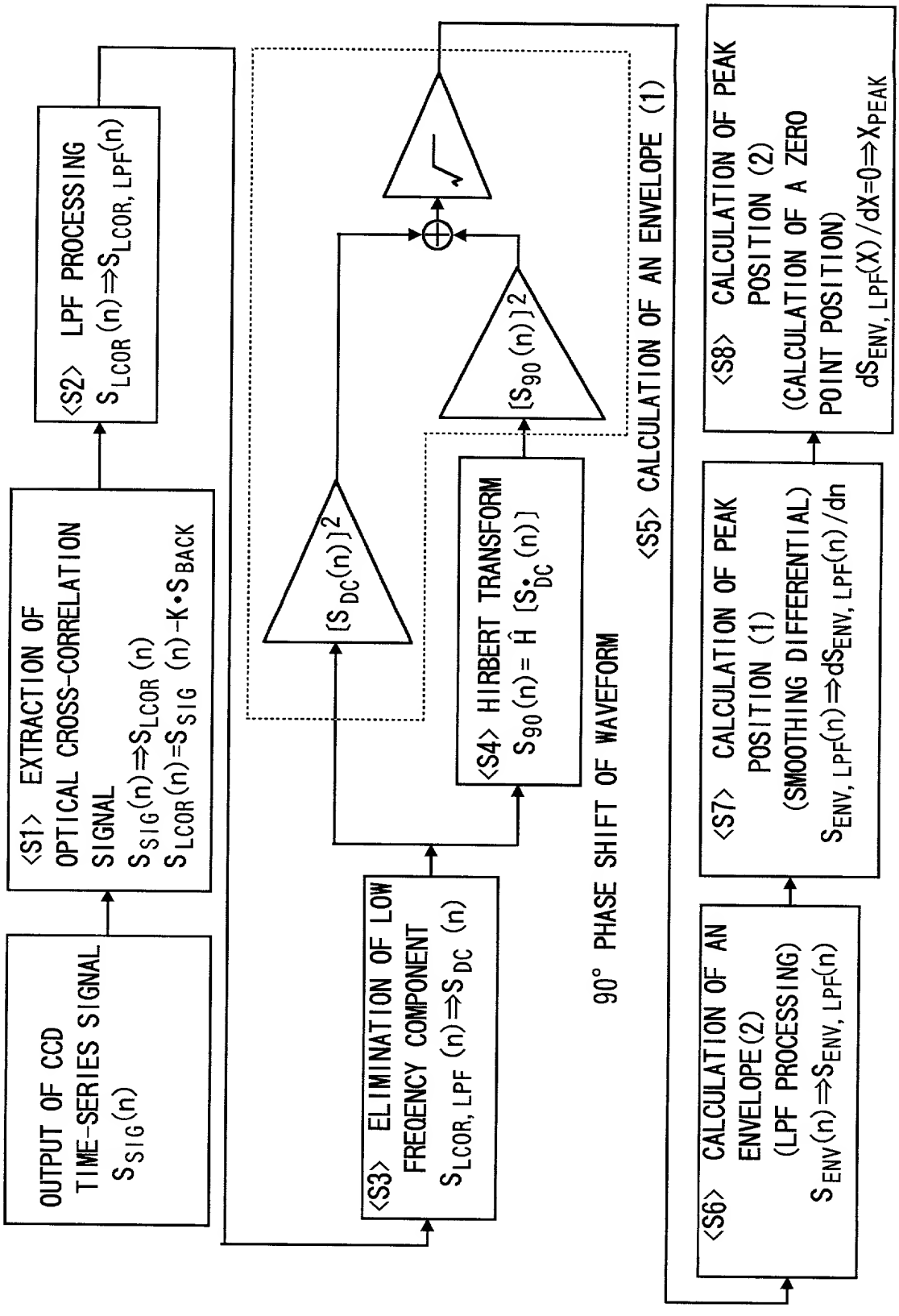

OUTPUT OF CCD
TIME-SERIES SIGNAL
$S_{SIG}(n)$
<S1> EXTRACTION OF OPTICAL CROSS-CORRELATION SIGNAL
$S_{SIG}(n) \Rightarrow S_{LCOR}(n)$
$S_{LCOR}(n) = S_{SIG}(n) - K \cdot S_{BACK}$
<S2> LPF PROCESSING
$S_{LCOR}(n) \Rightarrow S_{LCOR, LPF}(n)$
<S3> ELIMINATION OF LOW FREQENCY COMPONENT
$S_{LCOR, LPF}(n) \Rightarrow S_{DC}(n)$
<S4> HIRBERT TRANSFORM
$S_{90}(n) = \hat{H}\{S_{DC}(n)\}$
$[S_{DC}(n)]^2$
$[S_{90}(n)]^2$
90° PHASE SHIFT OF WAVEFORM
<S5> CALCULATION OF AN ENVELOPE (1)
<S6> CALCULATION OF AN ENVELOPE(2) (LPF PROCESSING)
$S_{ENV}(n) \Rightarrow S_{ENV, LPF}(n)$
<S7> CALCULATION OF PEAK POSITION (1) (SMOOTHING DIFFERENTIAL)
$S_{ENV, LPF}(n) \Rightarrow dS_{ENV, LPF}(n)/dn$
<S8> CALCULATION OF PEAK POSITION (2) (CALCULATION OF A ZERO POINT POSITION)
$dS_{ENV, LPF}(X)/dX = 0 \Rightarrow X_{PEAK}$

FIG. 14

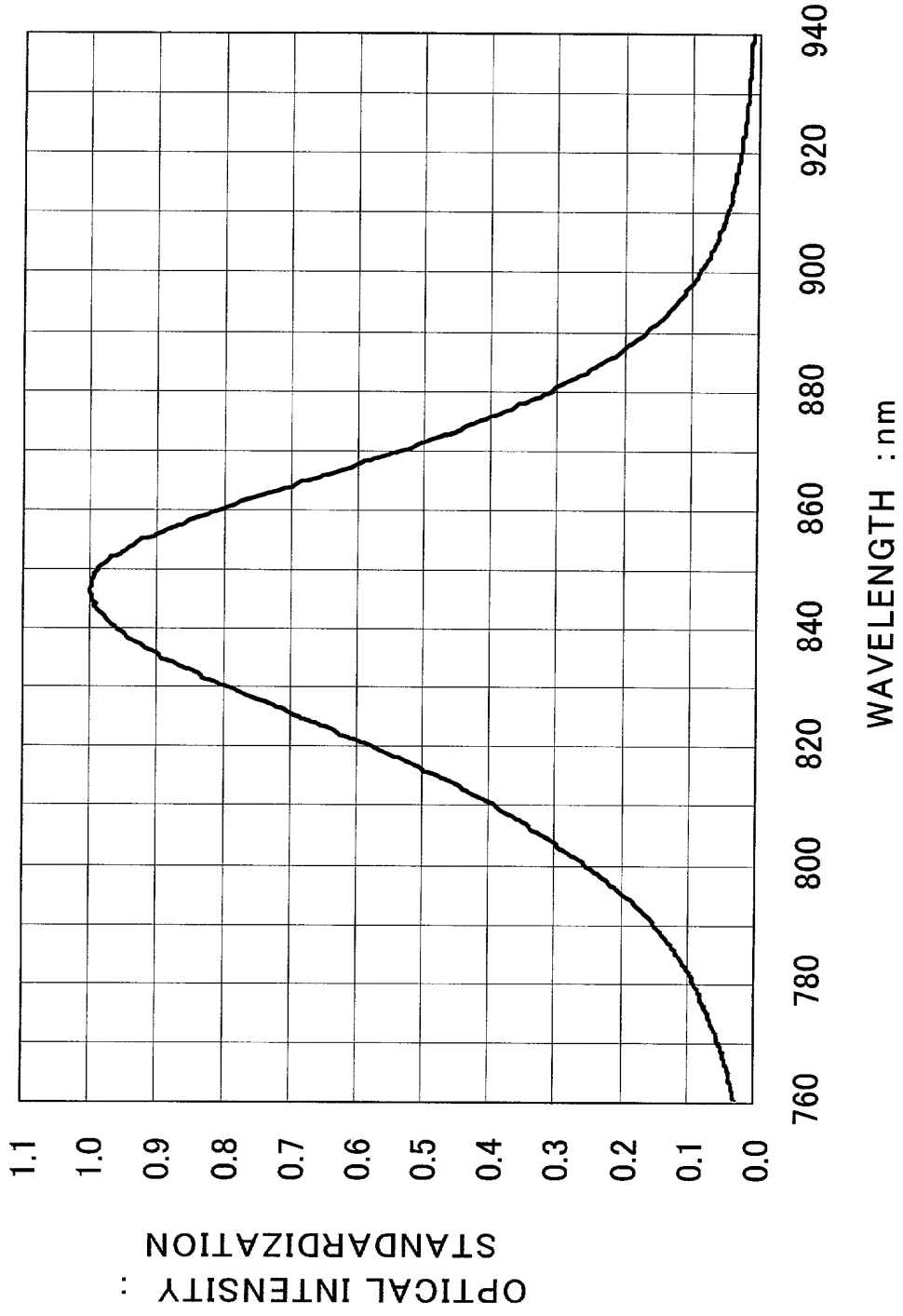

OPTICAL INTENSITY : STANDARDIZATION
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
760
780
800
820
840
860
880
900
920
940
WAVELENGTH : nm

FIG. 15

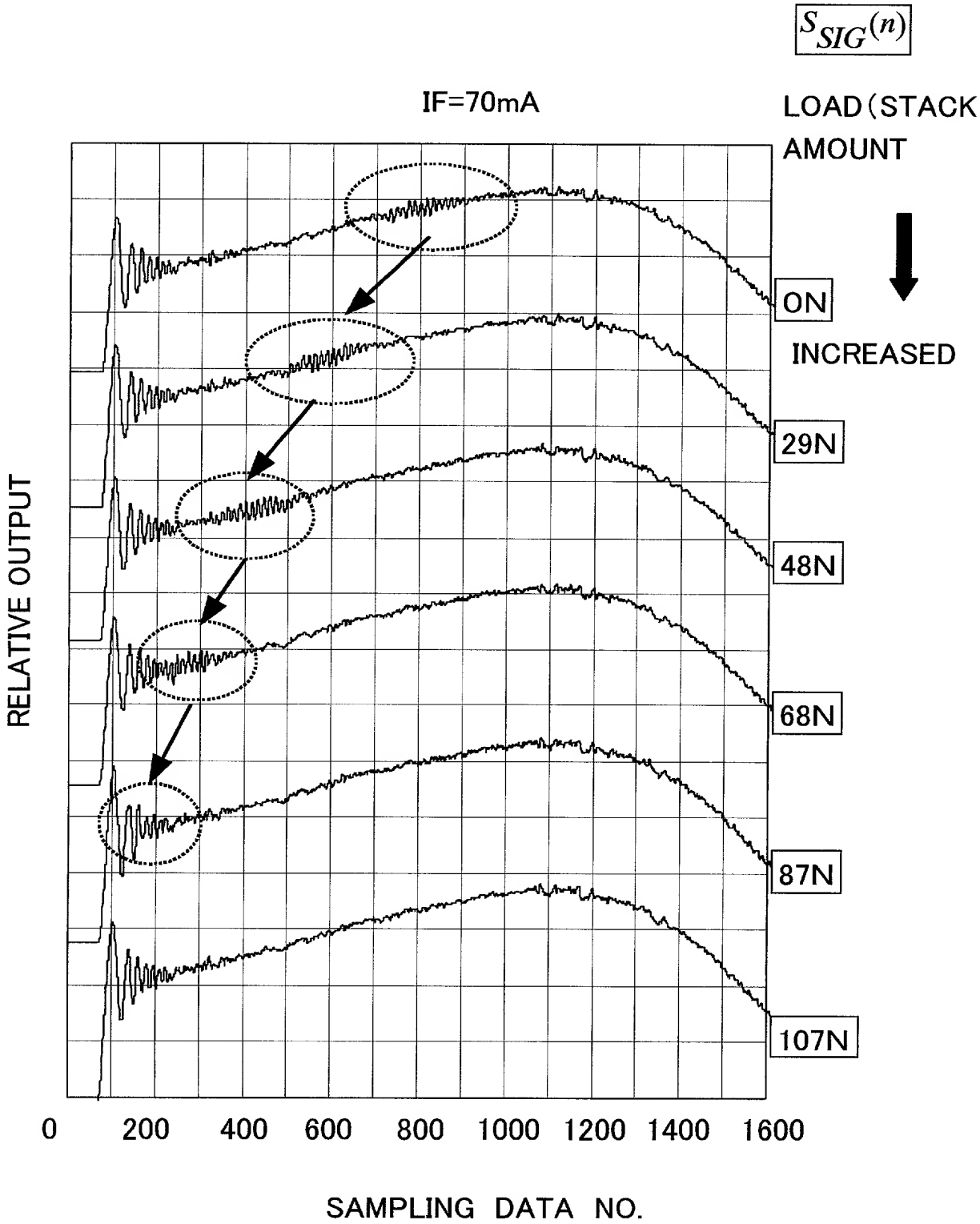

$S_{SIG}(n)$
IF=70mA
LOAD (STACK AMOUNT
INCREASED
ON
29N
48N
68N
87N
107N
RELATIVE OUTPUT
0
200
400
600
800
1000
1200
1400
1600
SAMPLING DATA NO.

FIG. 16

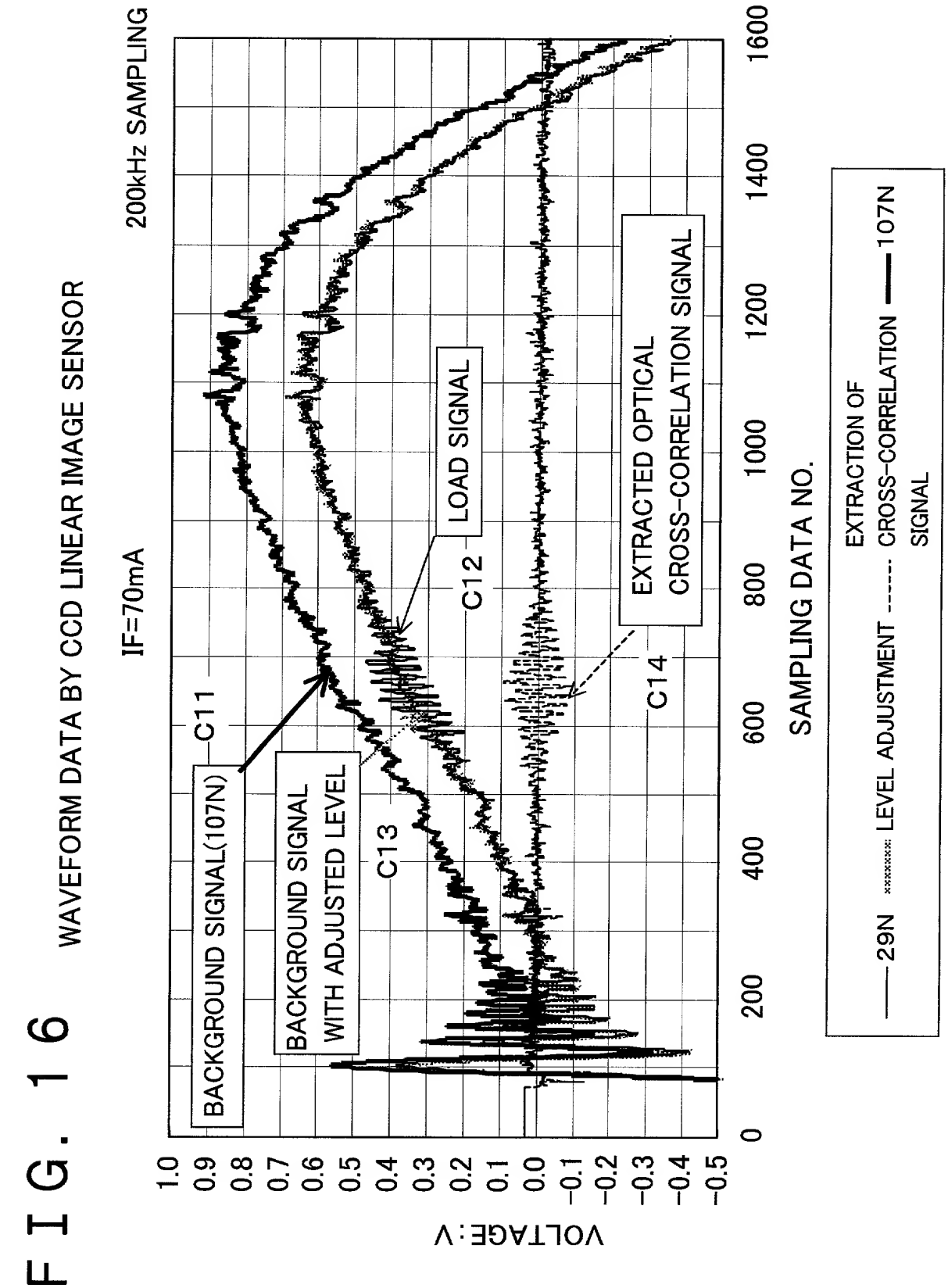

WAVEFORM DATA BY CCD LINEAR IMAGE SENSOR
IF=70mA
200kHz SAMPLING
BACKGROUND SIGNAL(107N)
C11
BACKGROUND SIGNAL WITH ADJUSTED LEVEL
C13
LOAD SIGNAL
C12
EXTRACTED OPTICAL CROSS-CORRELATION SIGNAL
C14
VOLTAGE:V
SAMPLING DATA NO.
EXTRACTION OF
29N LEVEL ADJUSTMENT CROSS-CORRELATION 107N
SIGNAL

FIG. 17

DETECTION OF OPTICAL CROSS-CORRELATION SIGNAL WITH CCD LINEAR IMAGE SENSOR

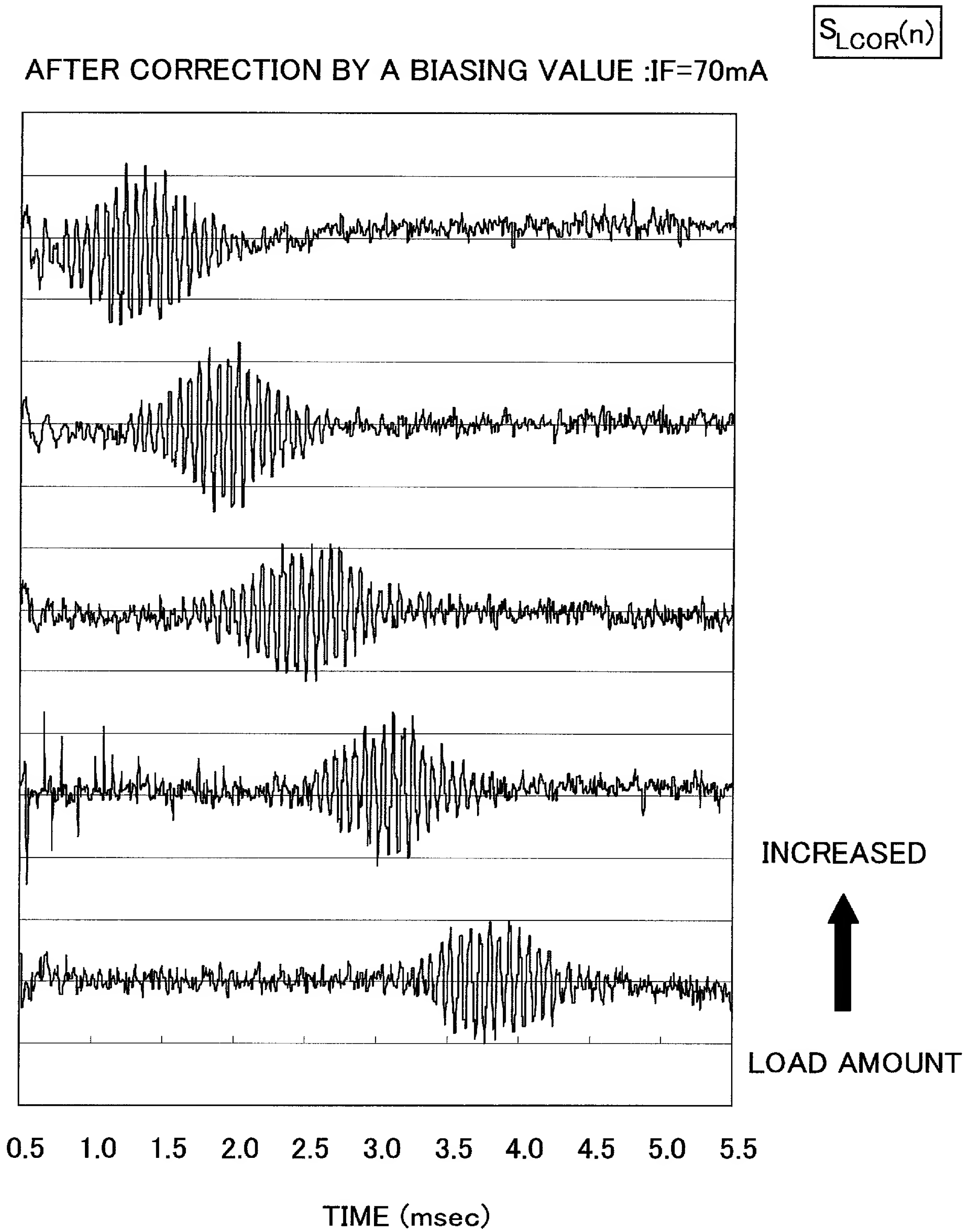


FIG. 18A

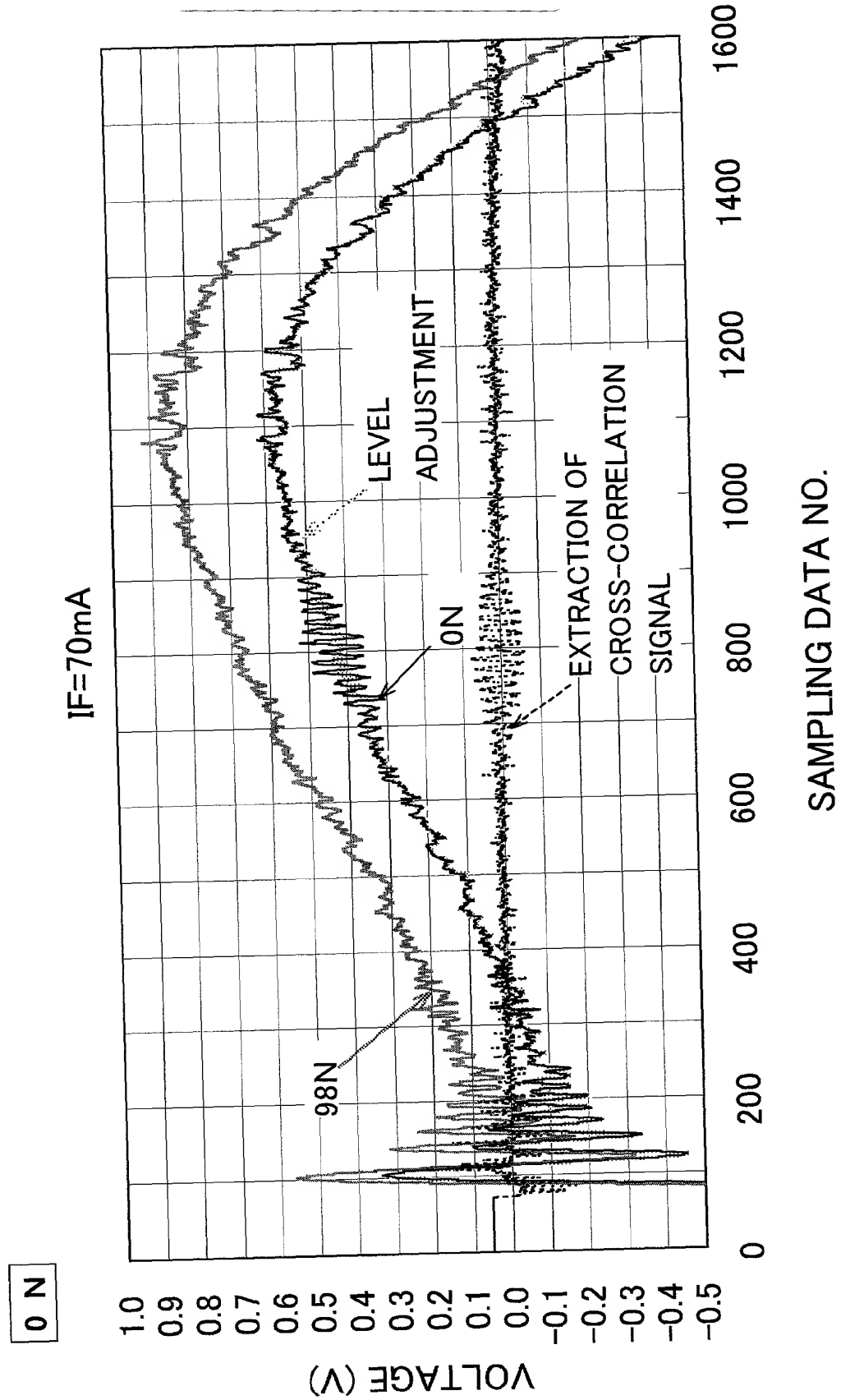

IF=70mA
LEVEL ADJUSTMENT ON
EXTRACTION OF CROSS-CORRELATION SIGNAL
98N
0 N
VOLTAGE (V)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
0
200
400
600
800
1000
1200
1400
1600
SAMPLING DATA NO.

FIG. 18B

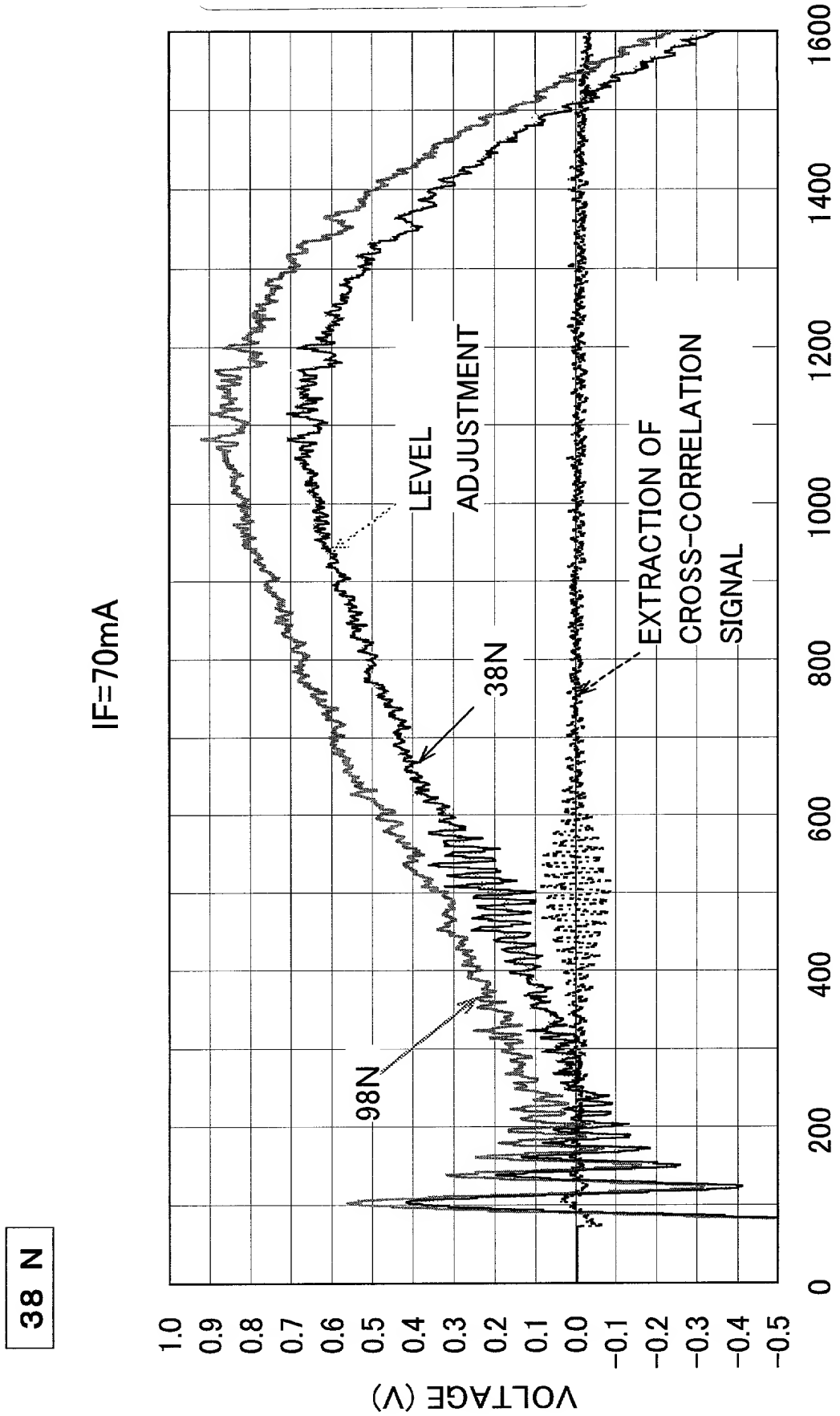

38 N
IF=70mA
98N
38N
LEVEL ADJUSTMENT
EXTRACTION OF CROSS-CORRELATION SIGNAL
VOLTAGE (V)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
0
200
400
600
800
1000
1200
1400
1600
SAMPLING DATA NO.

FIG. 18C

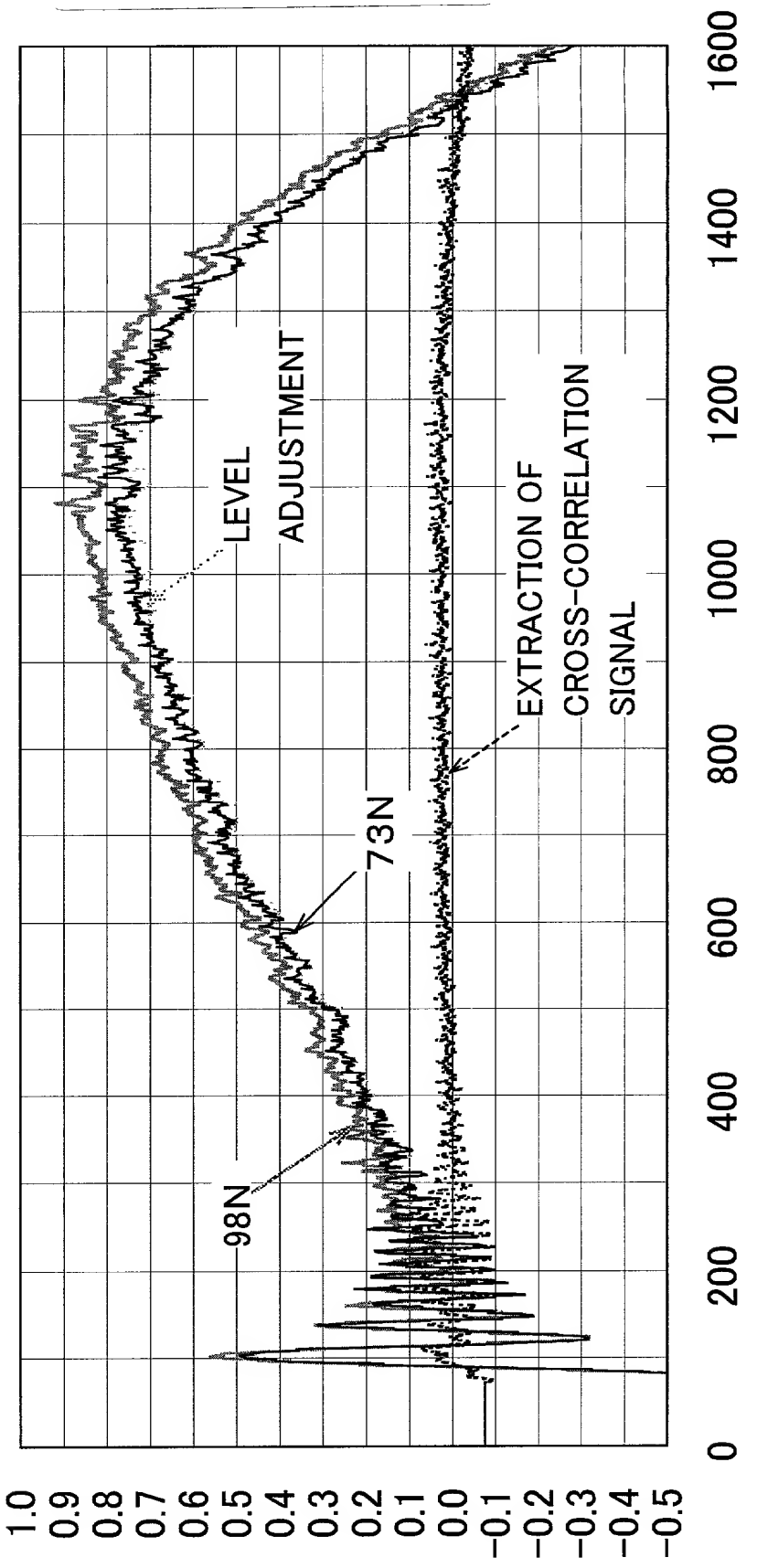

73 N
IF=70mA
LEVEL ADJUSTMENT
EXTRACTION OF CROSS-CORRELATION SIGNAL
73N
98N
VOLTAGE (V)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
0
200
400
600
800
1000
1200
1400
1600
SAMPLING DATA NO.

FIG. 19

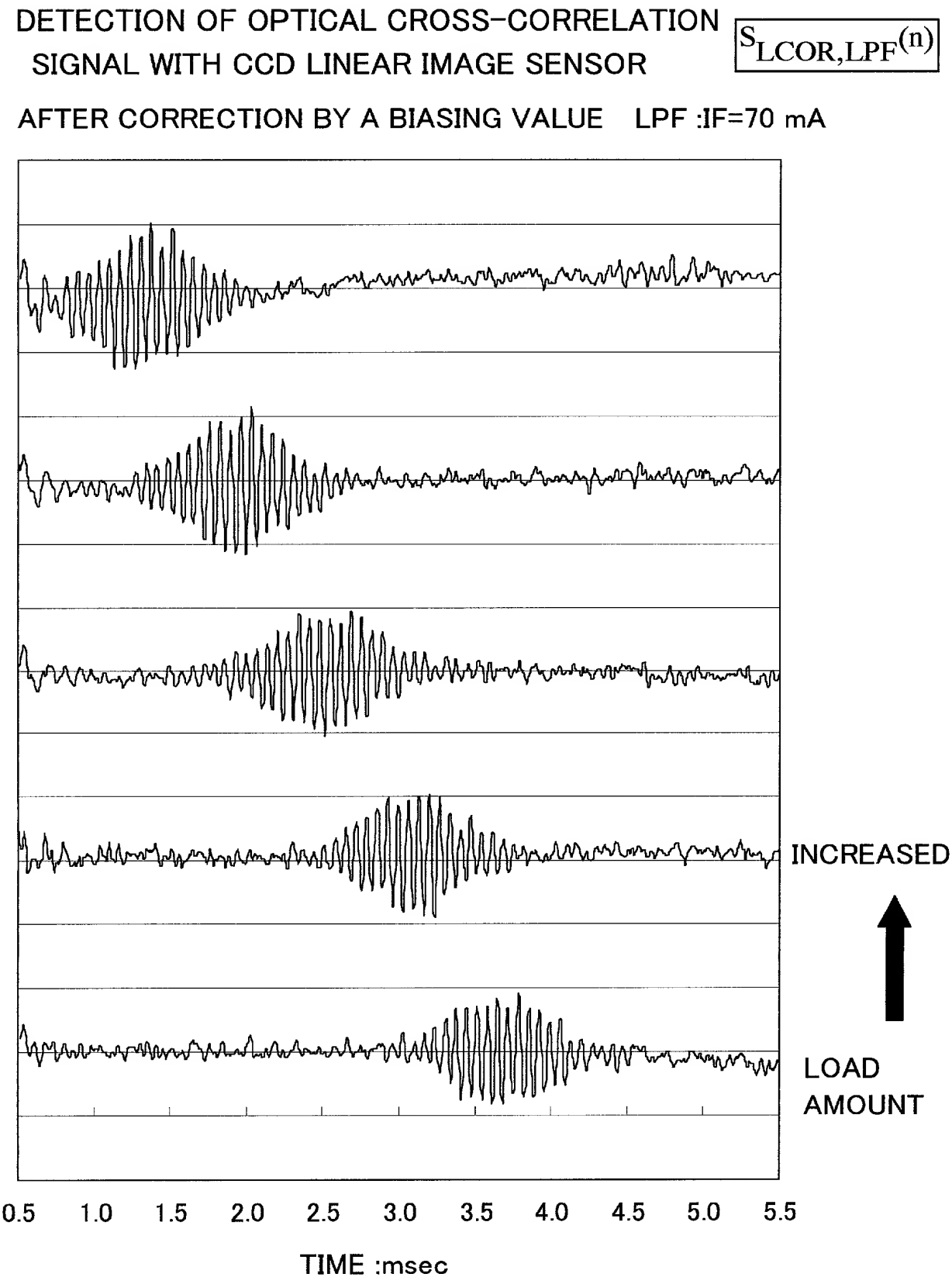

DETECTION OF OPTICAL CROSS-CORRELATION SIGNAL WITH CCD LINEAR IMAGE SENSOR
$S_{LCOR,LPF}^{(n)}$
AFTER CORRECTION BY A BIASING VALUE LPF :IF=70 mA
INCREASED
LOAD AMOUNT
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5
TIME :msec

FIG. 20A

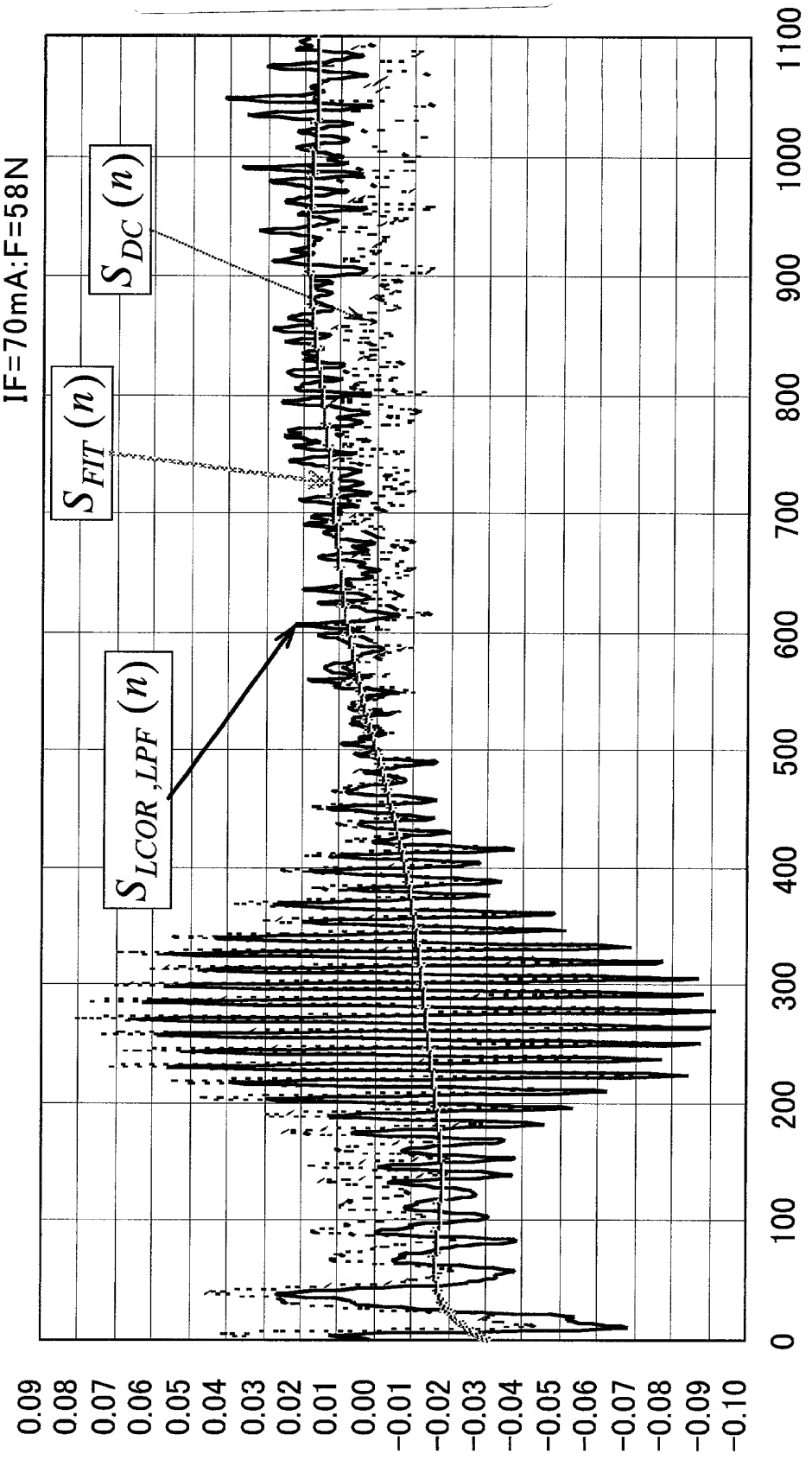

ANALYSIS OF WHITE INTERFERENCE MEASURED DATA WITH CCD LINEAR IMAGE SENSOR
IF=70mA:F=58N
$S_{DC}(n)$
$S_{FIT}(n)$
$S_{LCOR,LPF}(n)$
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03
−0.04
−0.05
−0.06
−0.07
−0.08
−0.09
−0.10
0
100
200
300
400
500
600
700
800
900
1000
1100
SAMPLING DATA NO.

FIG. 20B

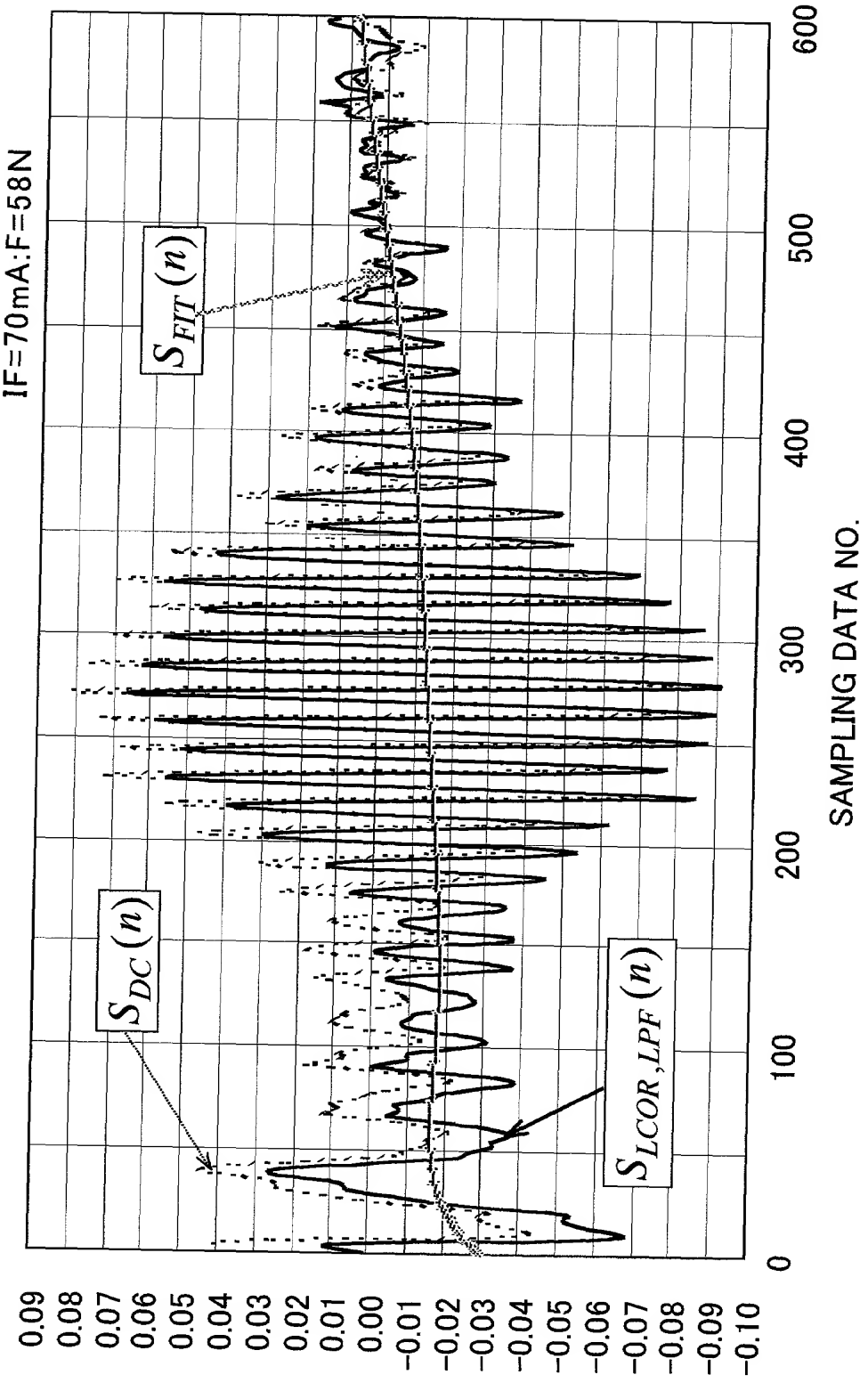

ANALYSIS OF WHITE INTERFERENCE MEASURED DATA WITH CCD LINEAR IMAGE SENSOR
IF=70mA:F=58N
$S_{FIT}(n)$
$S_{DC}(n)$
$S_{LCOR,LPF}(n)$
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03
−0.04
−0.05
−0.06
−0.07
−0.08
−0.09
−0.10
0
100
200
300
400
500
600
SAMPLING DATA NO.

FIG. 21

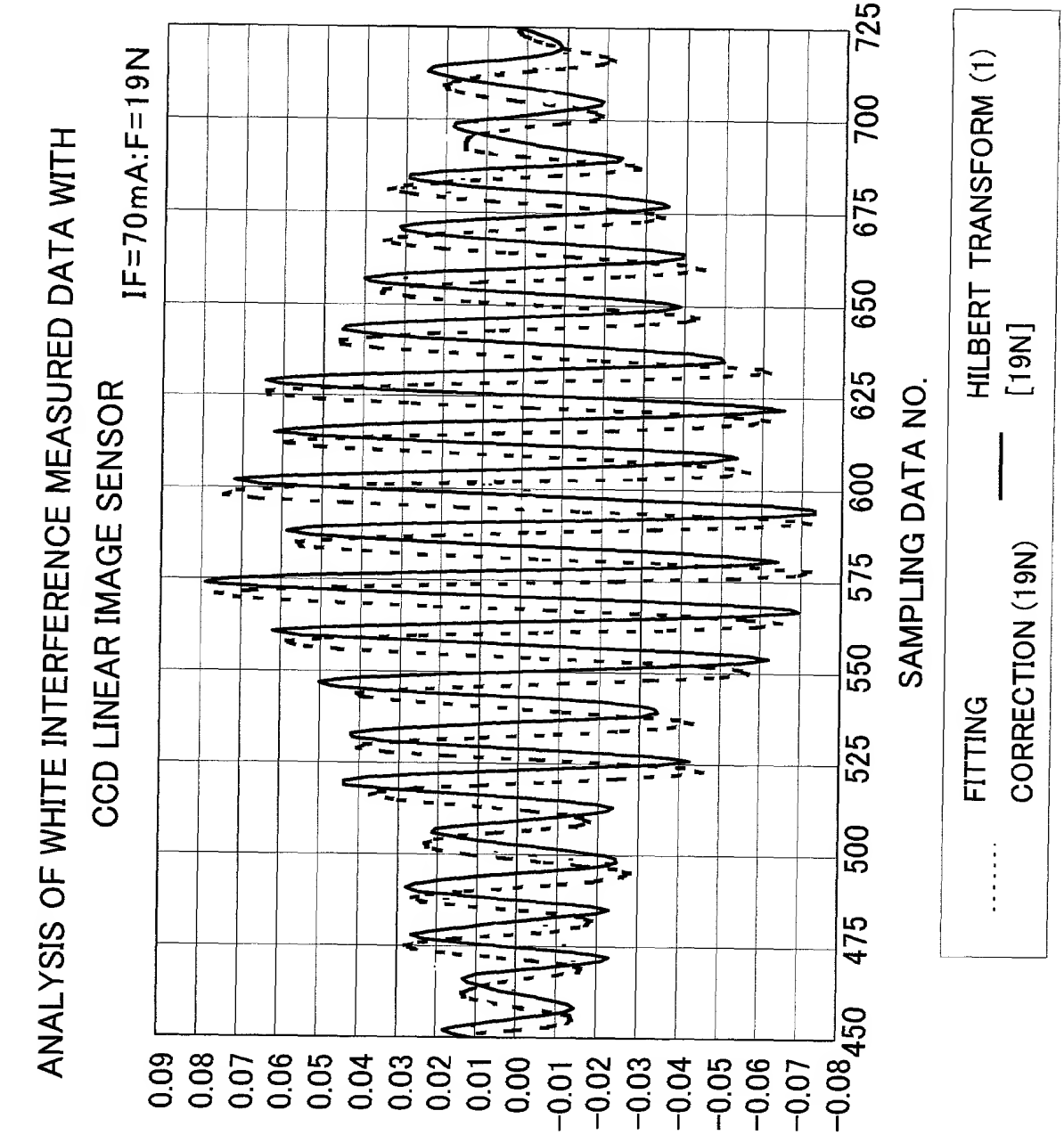

ANALYSIS OF WHITE INTERFERENCE MEASURED DATA WITH CCD LINEAR IMAGE SENSOR
IF=70mA:F=19N
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03
−0.04
−0.05
−0.06
−0.07
−0.08
450
475
500
525
550
575
600
625
650
675
700
725
SAMPLING DATA NO.
FITTING
CORRECTION (19N)
HILBERT TRANSFORM (1)
[19N]

FIG. 22

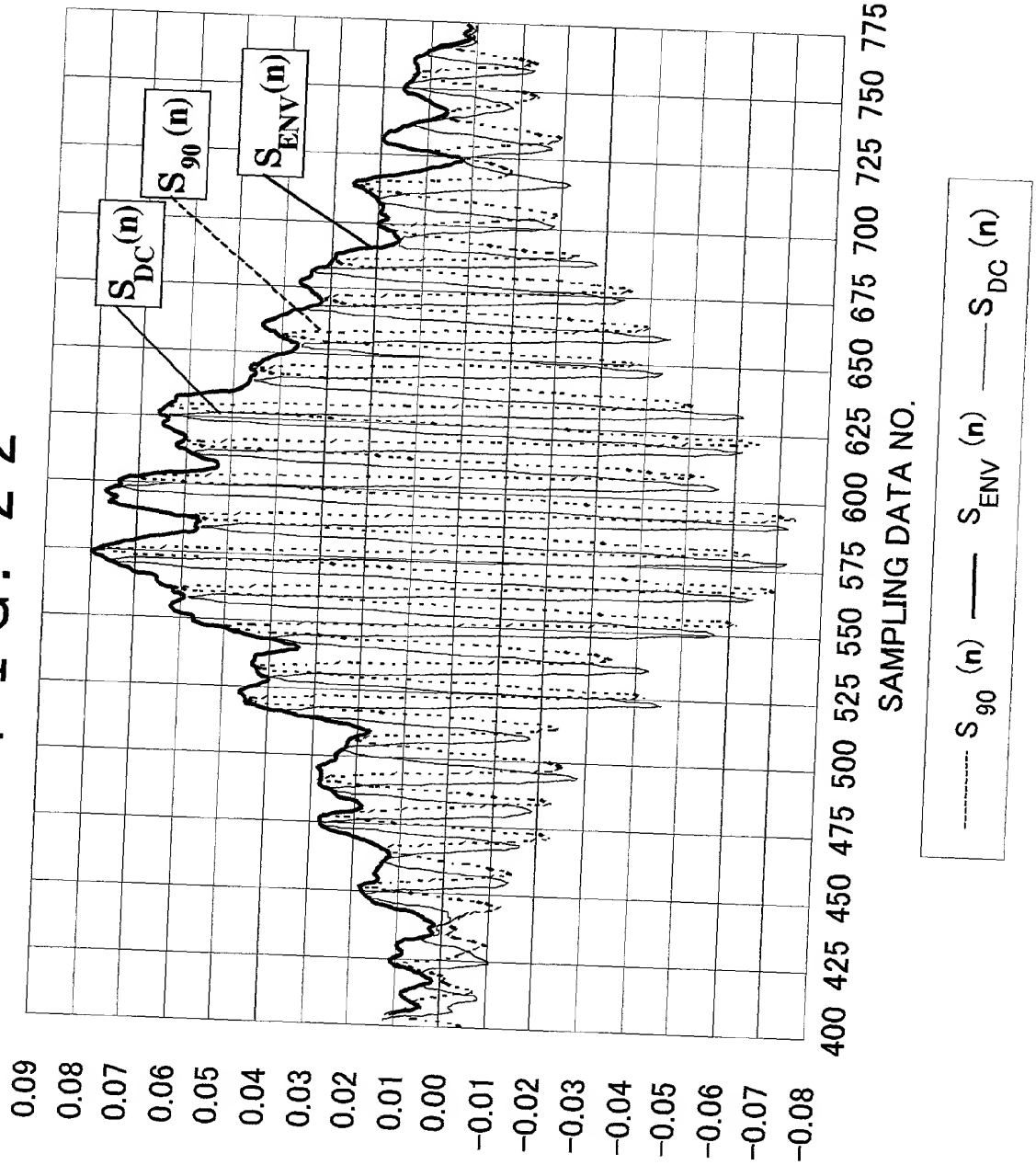
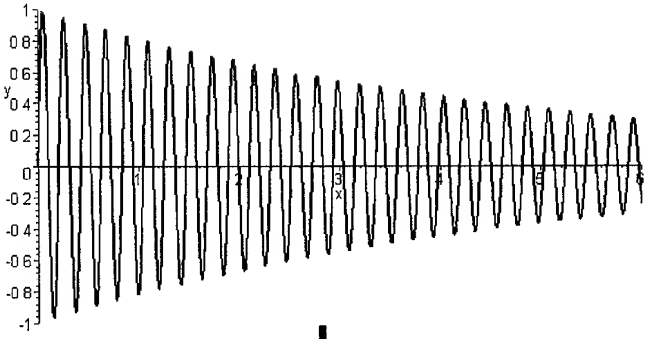

$S_{DC}(n)$
$S_{90}(n)$
$S_{ENV}(n)$
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03
−0.04
−0.05
−0.06
−0.07
−0.08
400 425 450 475 500 525 550 575 600 625 650 675 700 725 750 775
SAMPLING DATA NO.
$S_{90}(n)$ —— $S_{ENV}(n)$ —— $S_{DC}(n)$

FIG. 23

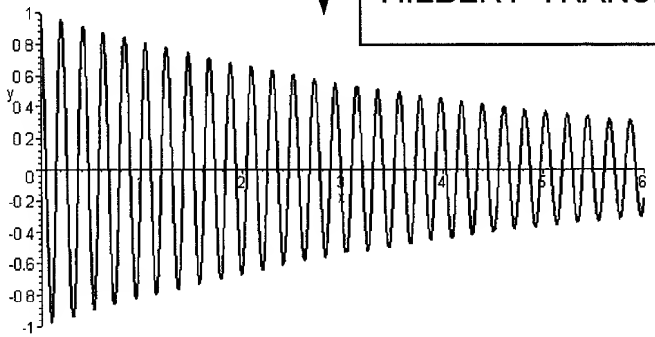
INPULSE RESPONDING WAVEFORM

$$h(t) = A \cdot \exp(-\alpha \cdot t) \cdot \sin(\omega_0 \cdot t)$$



$\hat{H}$

HILBERT TRANSFORM

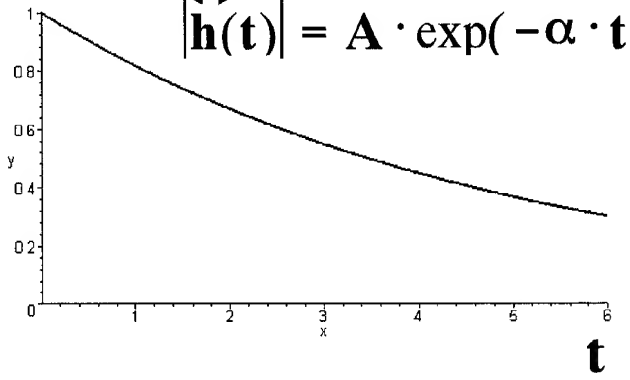


$$\tilde{h}(t) = A \cdot \exp(-\alpha \cdot t) \cdot \cos(\omega_0 \cdot t)$$

$|\overleftrightarrow{h}(t)|$

ENVELOPE

$$|\overleftrightarrow{h}(t)| = A \cdot \exp(-\alpha \cdot t)$$



$$\overleftrightarrow{h}(t) = h(t) + j \cdot \tilde{h}(t)$$

$$|\overleftrightarrow{h}(t)| = \sqrt{[h(t)]^2 + [\tilde{h}(t)]^2}$$

FIG. 24

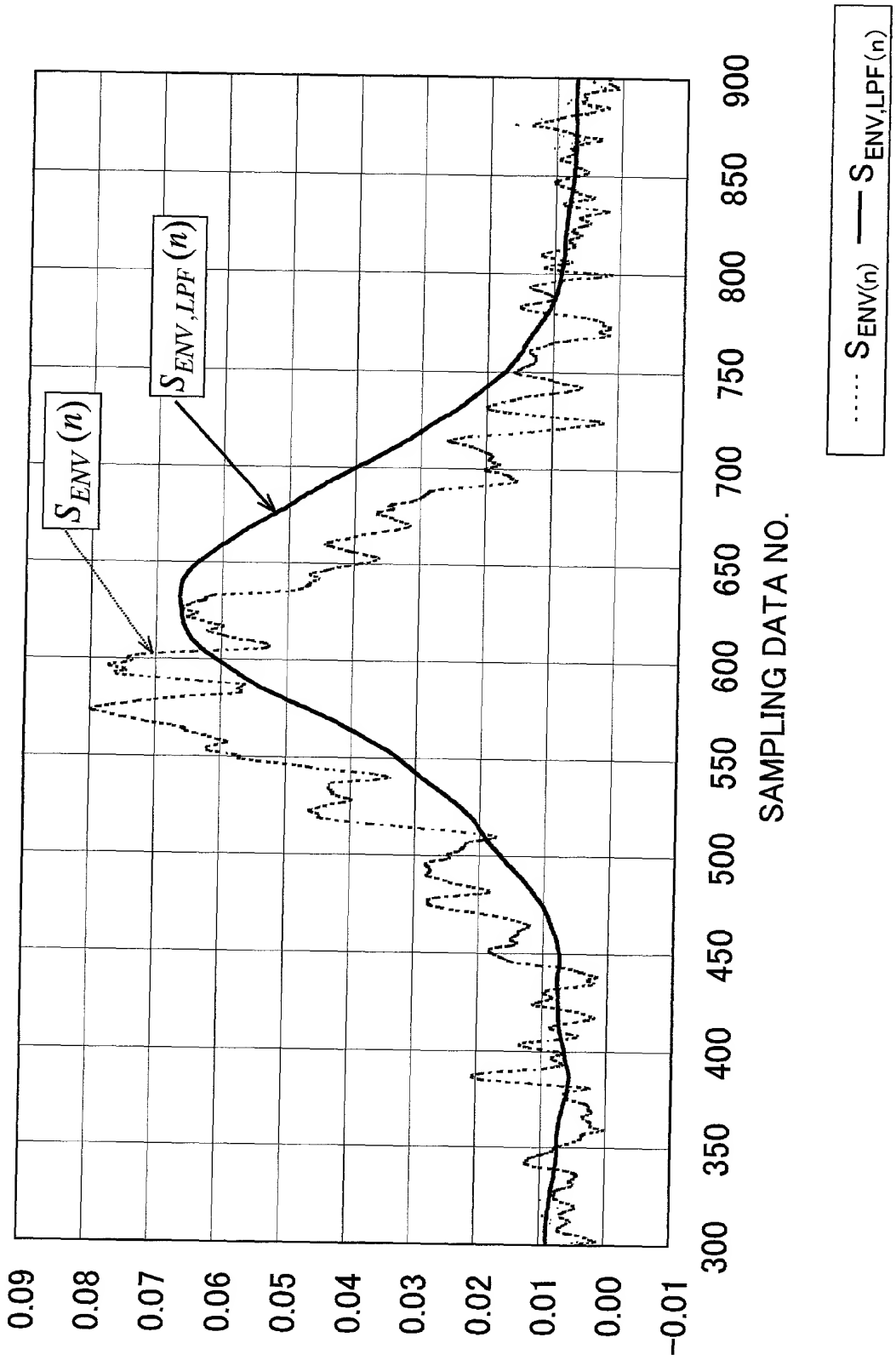

$S_{ENV}(n)$
$S_{ENV,LPF}(n)$
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
−0.01
300
350
400
450
500
550
600
650
700
750
800
850
900
SAMPLING DATA NO.
$S_{ENV(n)}$
$S_{ENV,LPF(n)}$

FIG. 25

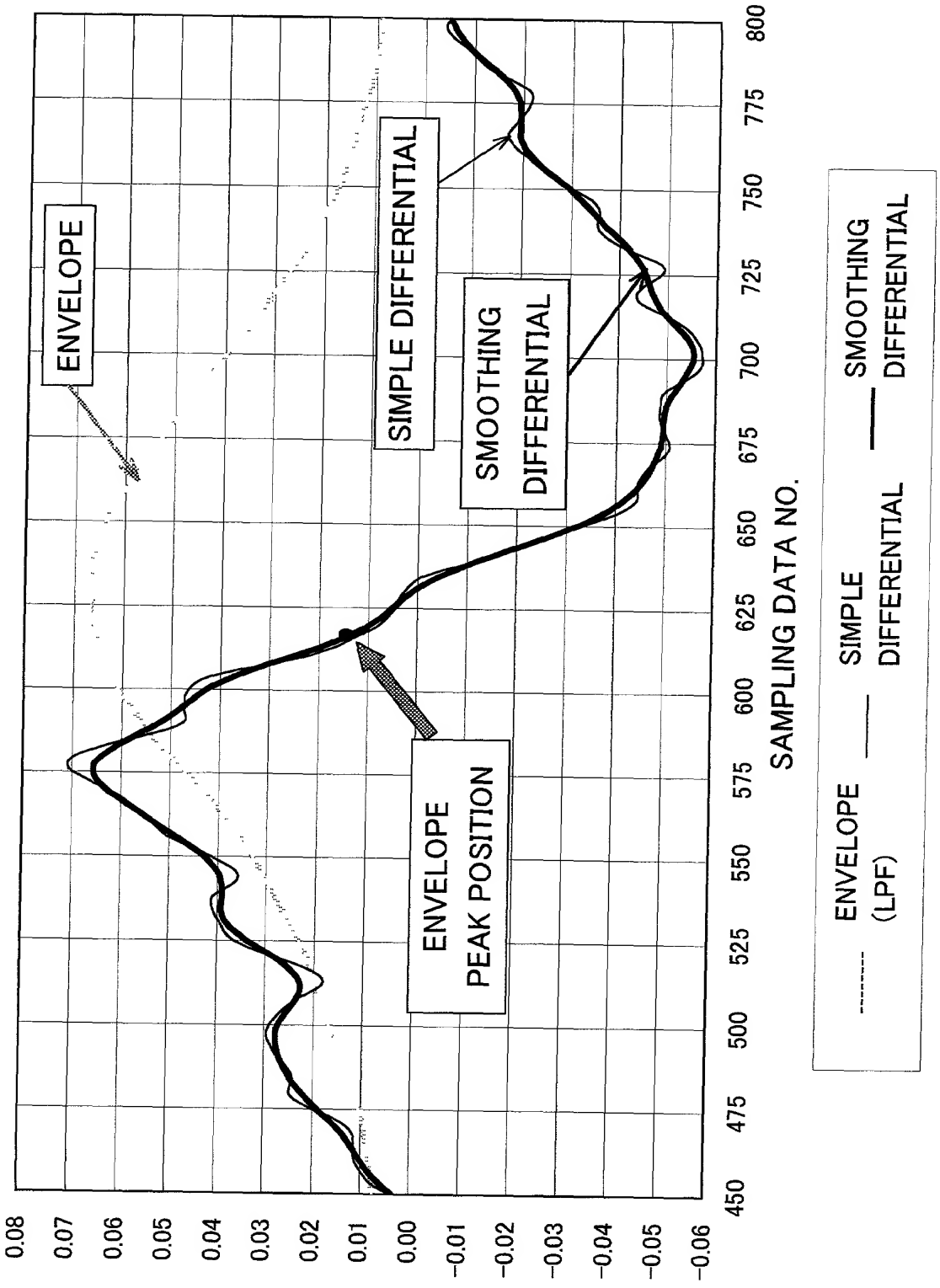

ENVELOPE
SIMPLE DIFFERENTIAL
SMOOTHING DIFFERENTIAL
ENVELOPE PEAK POSITION
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03
−0.04
−0.05
−0.06
450
475
500
525
550
575
600
625
650
675
700
725
750
775
800
SAMPLING DATA NO.
ENVELOPE (LPF)
SIMPLE DIFFERENTIAL
SMOOTHING DIFFERENTIAL

FIG. 26

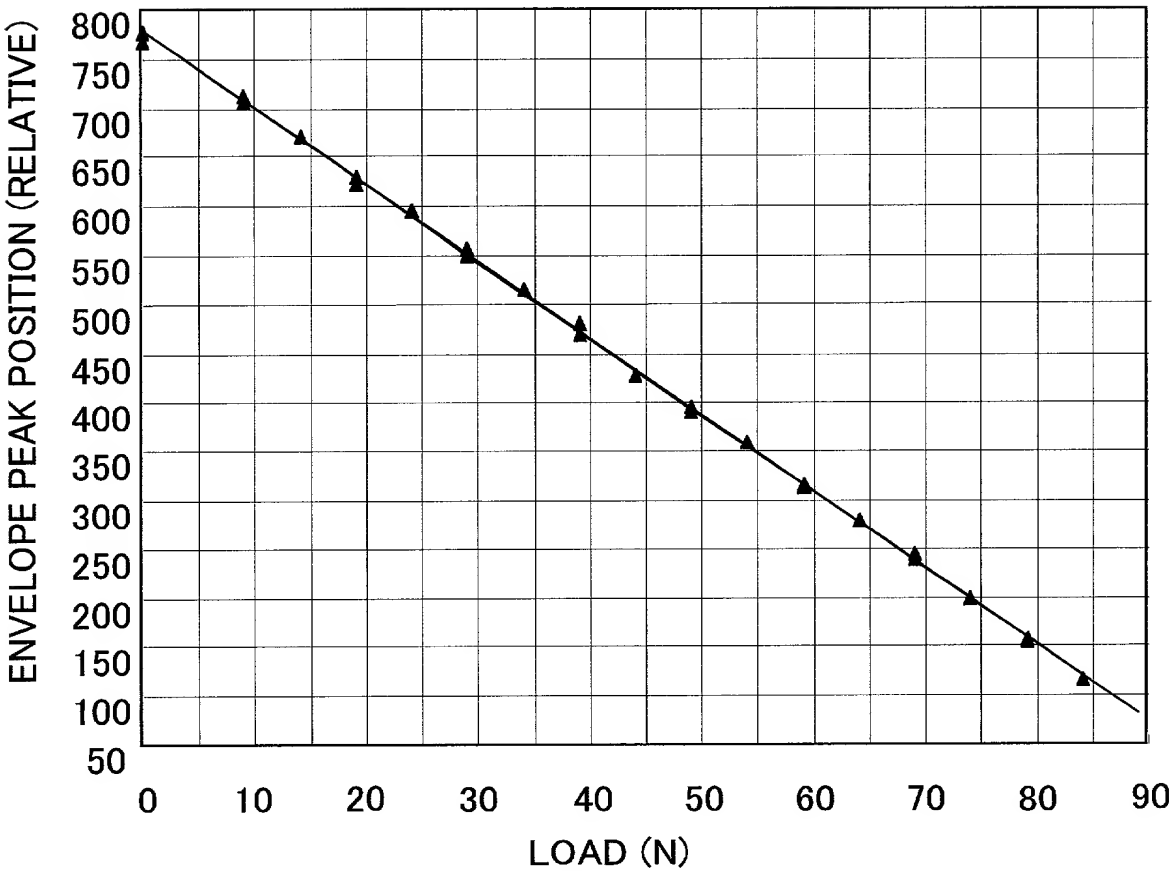

ENVELOPE PEAK POSITION (RELATIVE)
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
10
20
30
40
50
60
70
80
90
LOAD (N)

FIG. 27A PRIOR ART

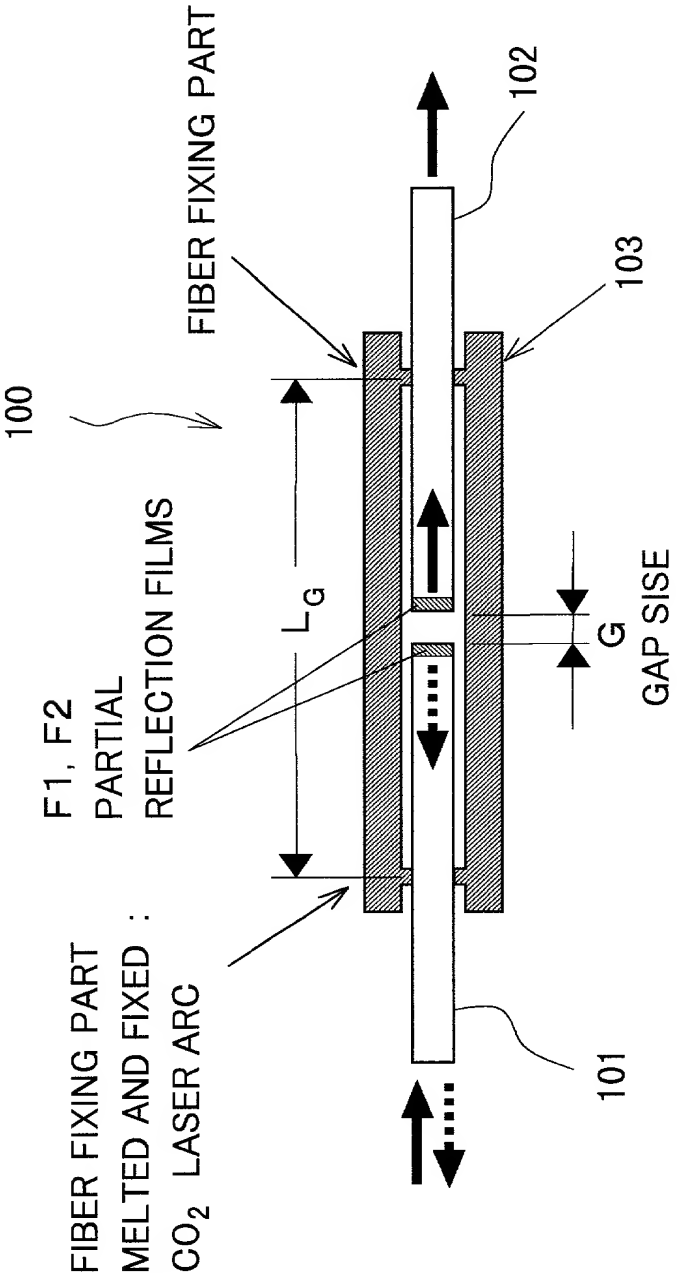


FIG. 27B PRIOR ART

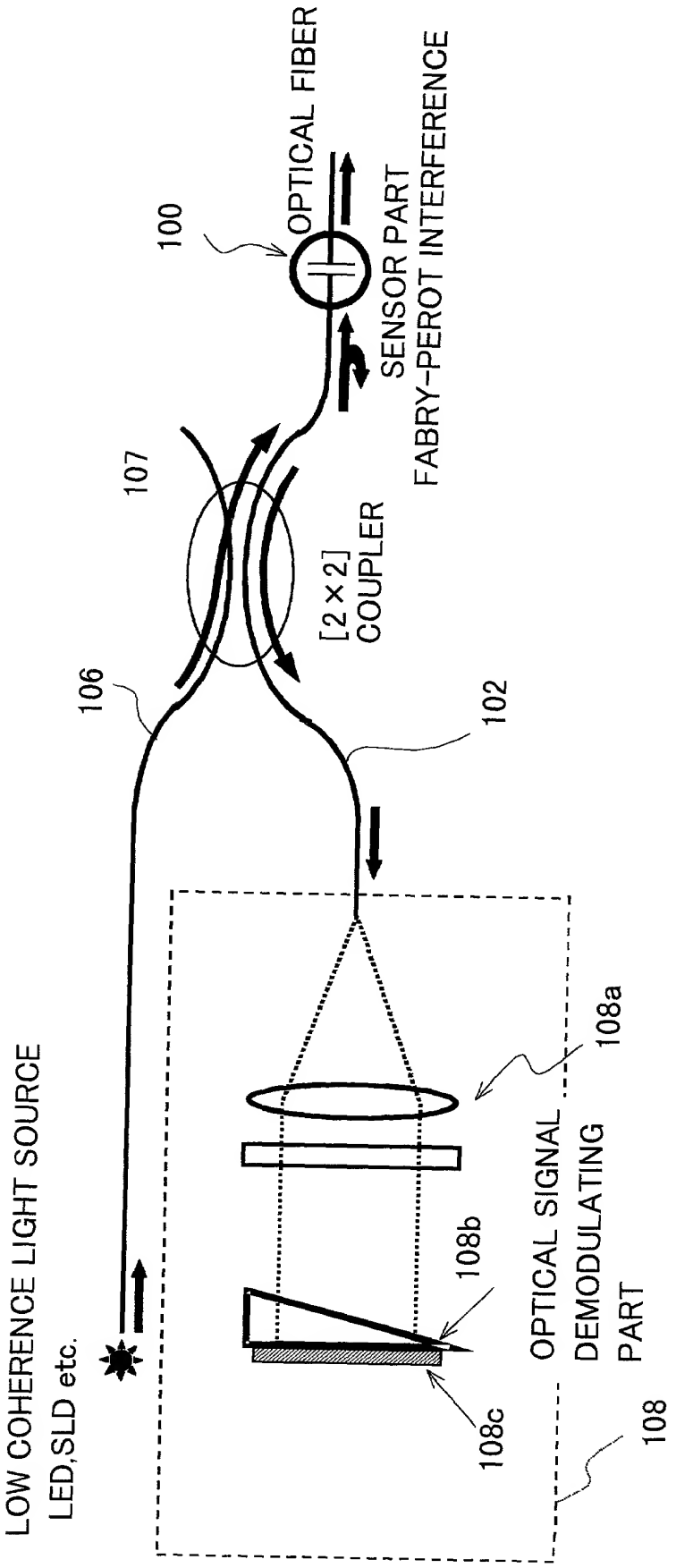


FIG. 28 PRIOR ART

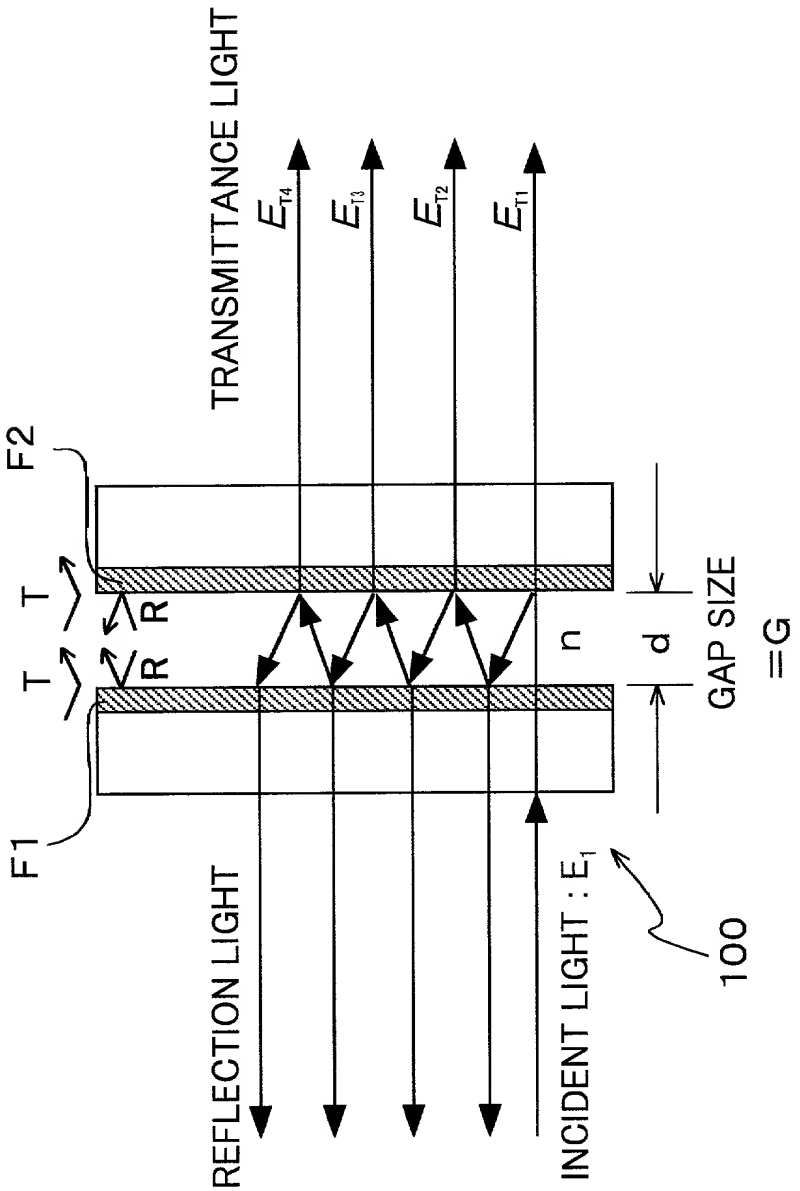


FIG. 29 PRIOR ART

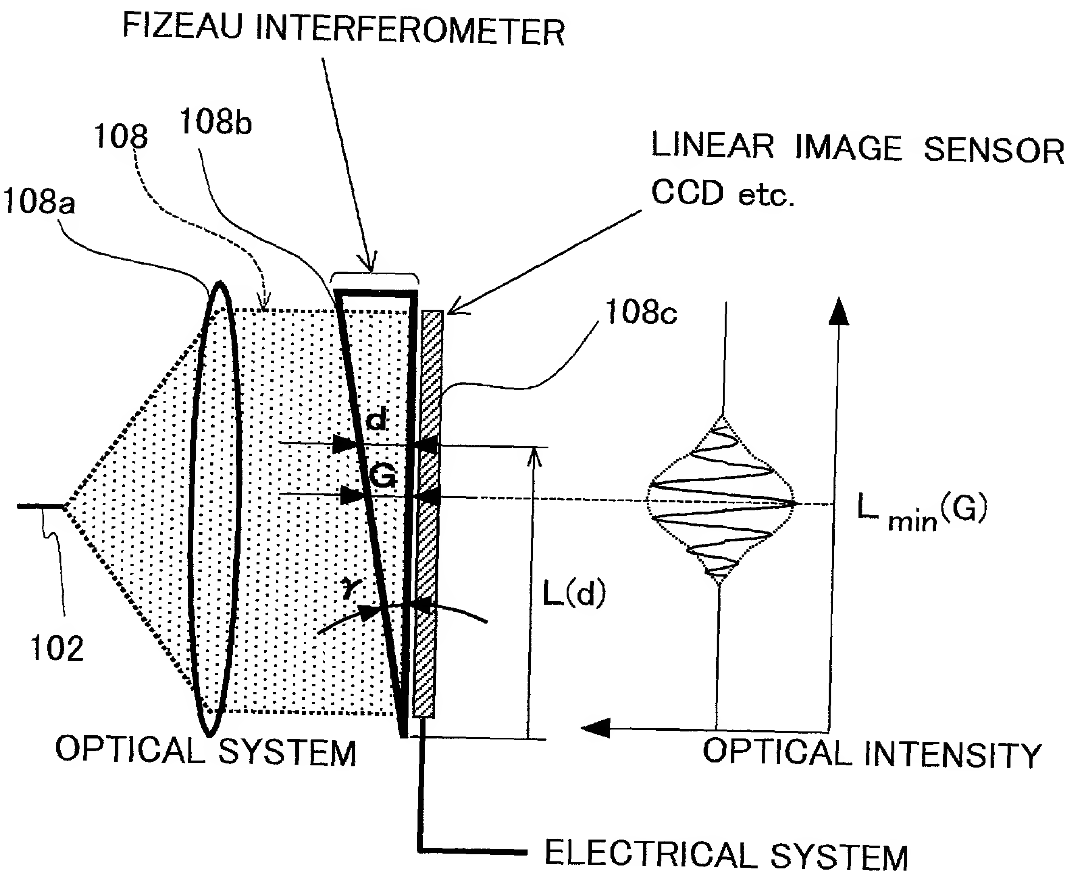


FIG. 30 PRIOR ART

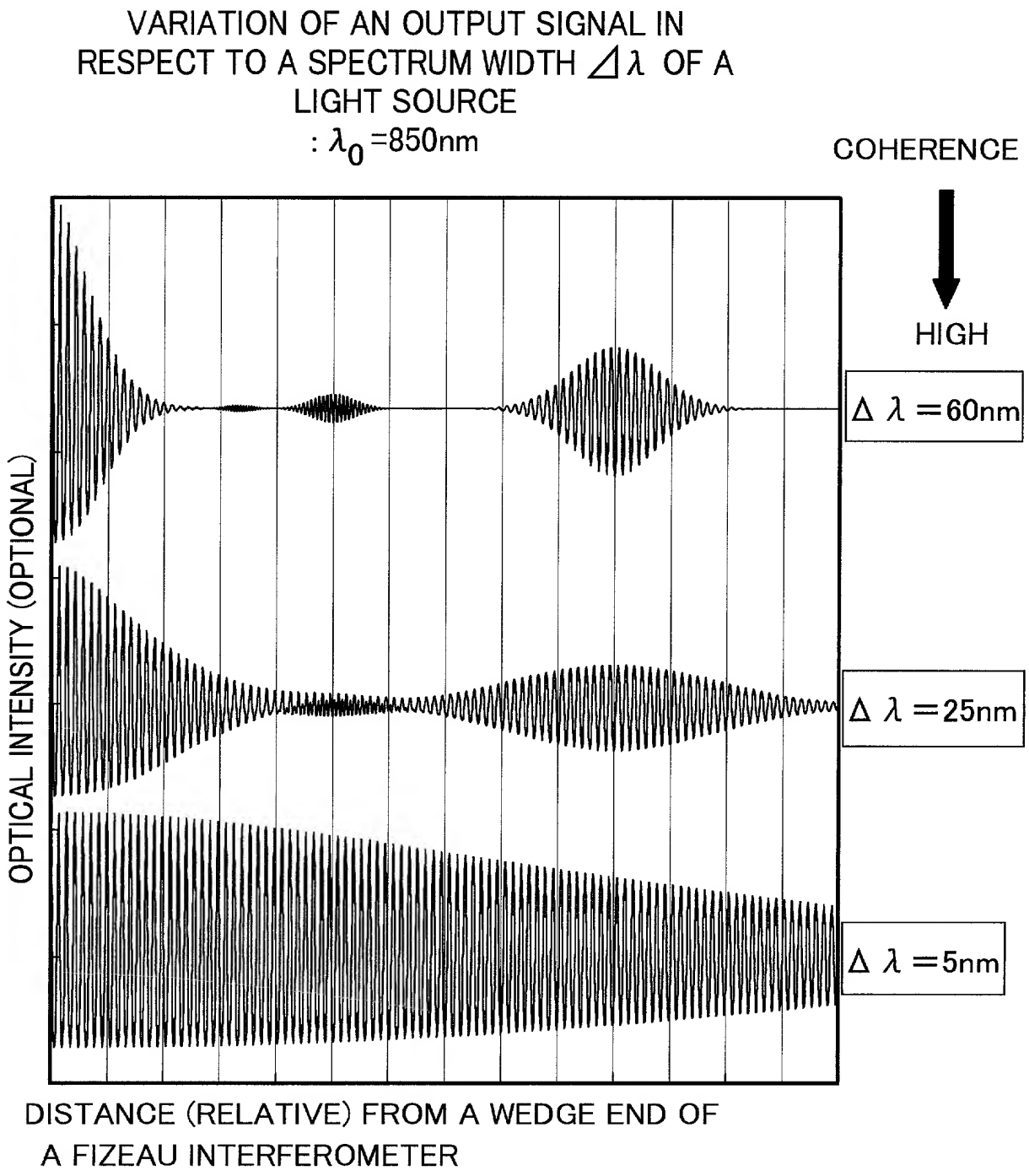


FIG. 31 PRIOR ART

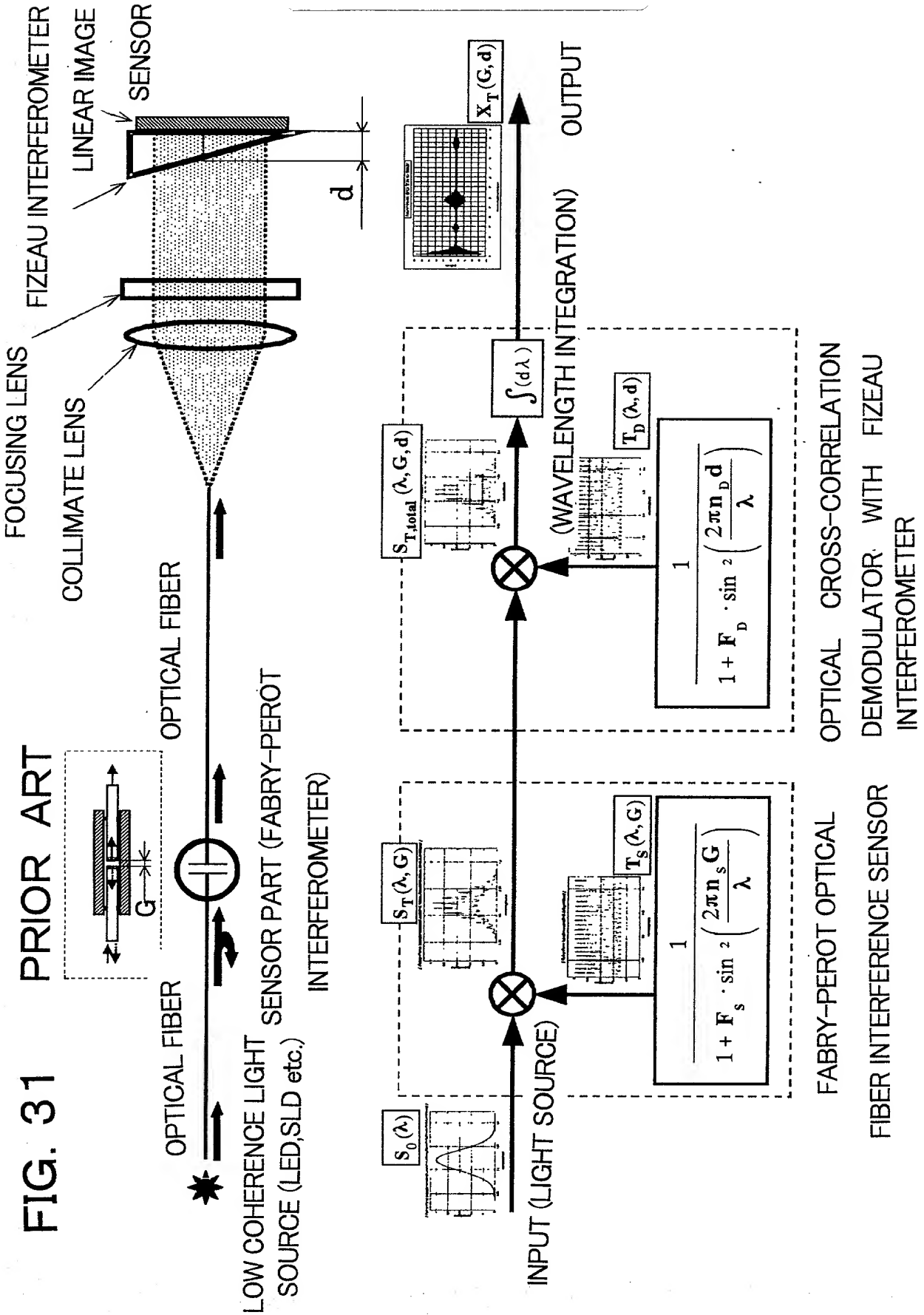


FIG. 32 PRIOR ART

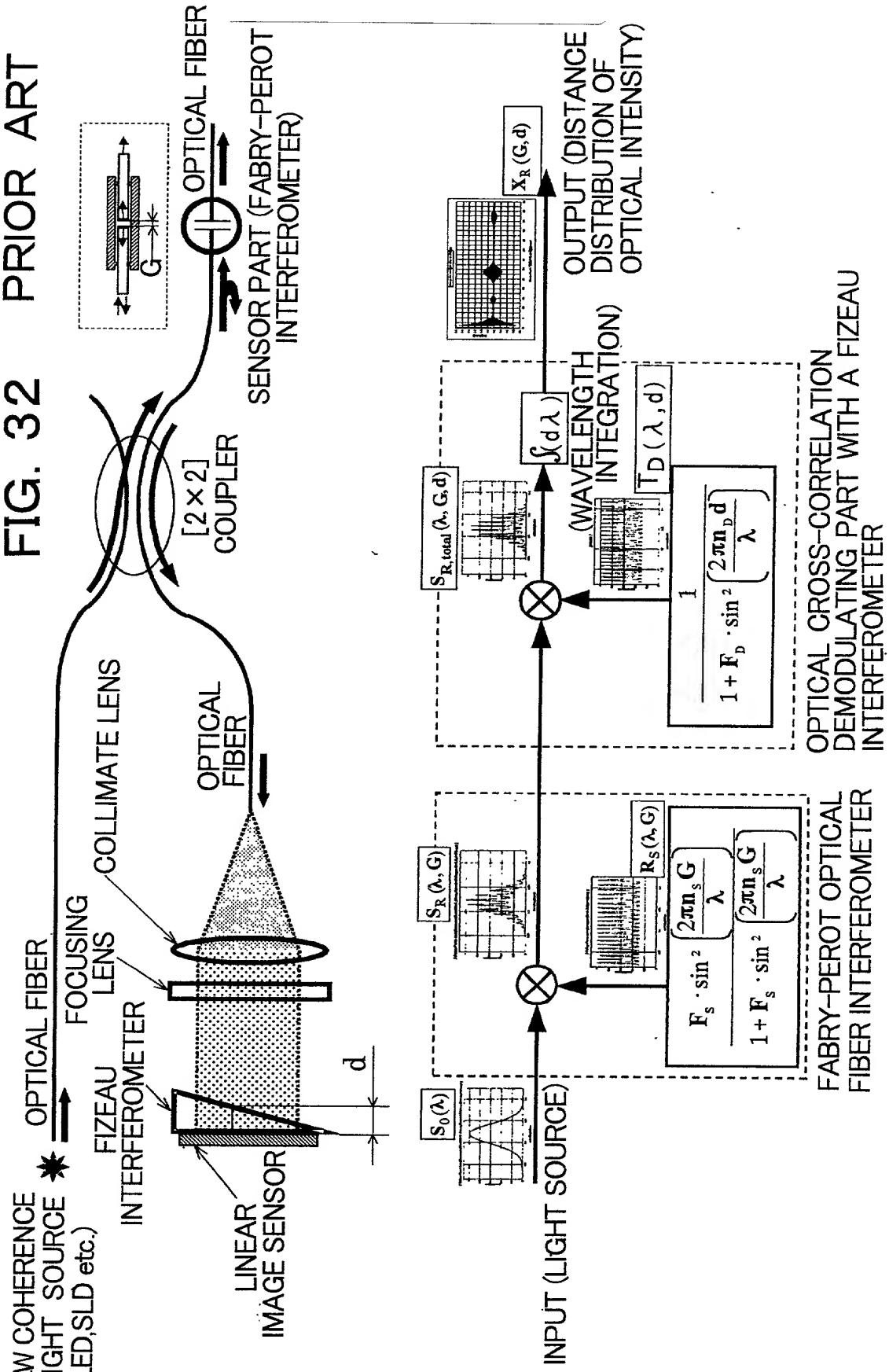


FIG. 33A PRIOR ART

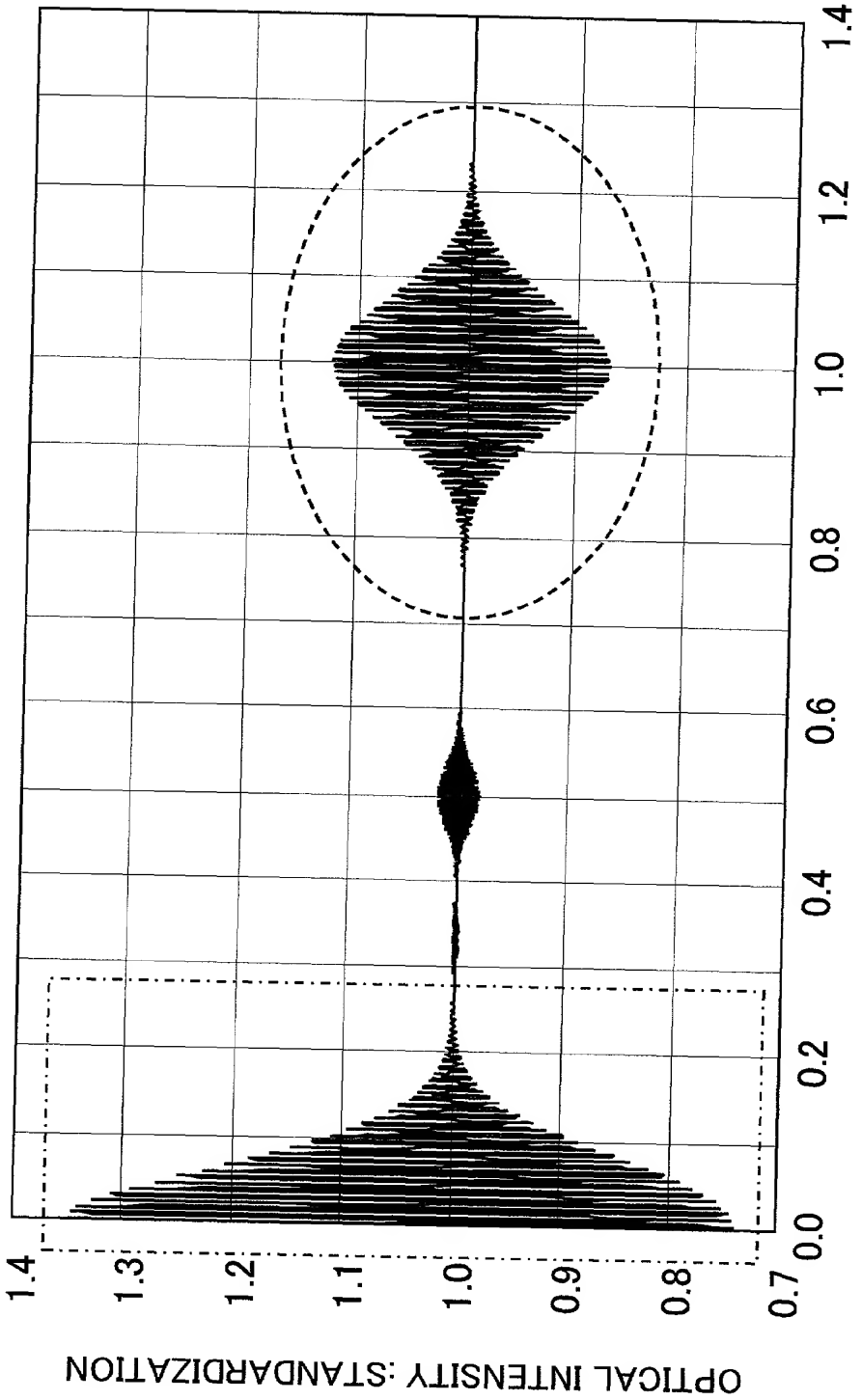


FIG. 33B PRIOR ART

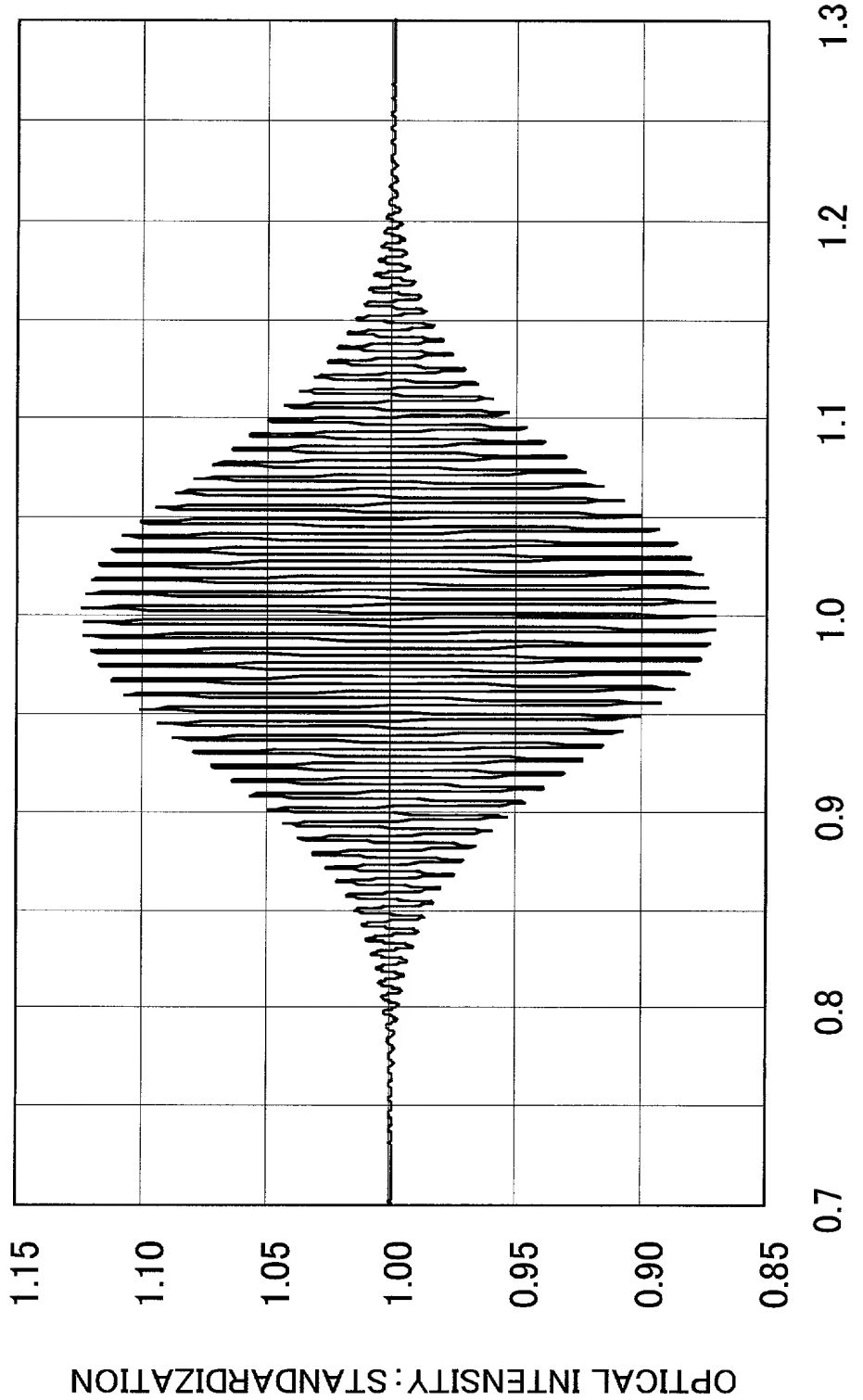


FIG. 34A PRIOR ART

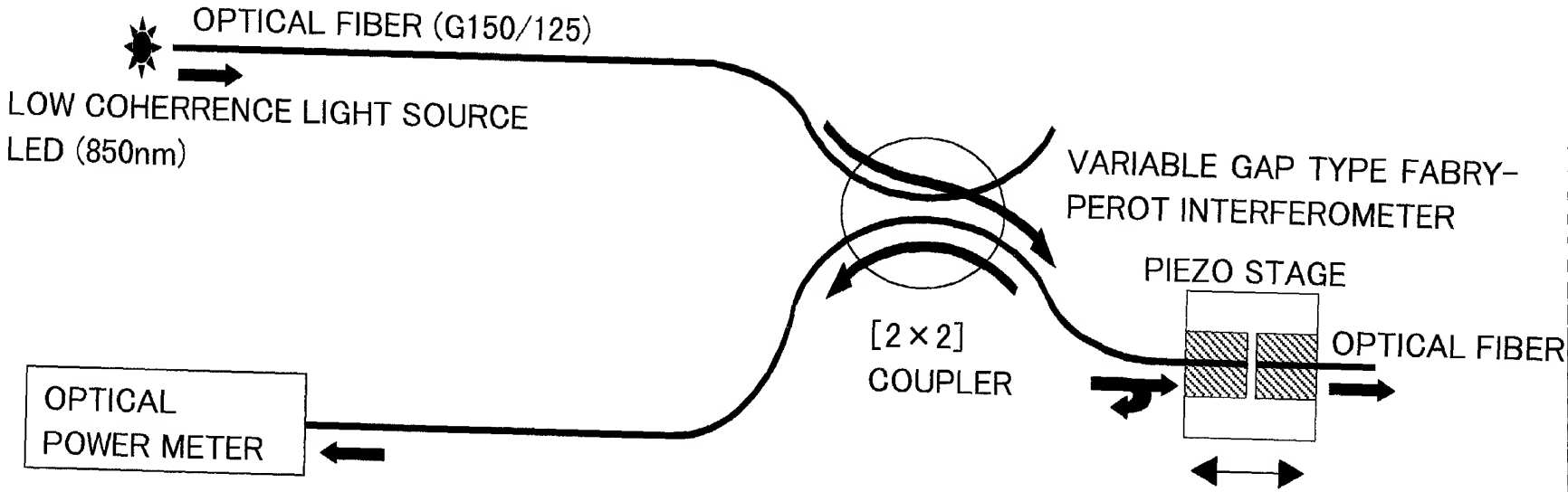


FIG. 34B PRIOR ART

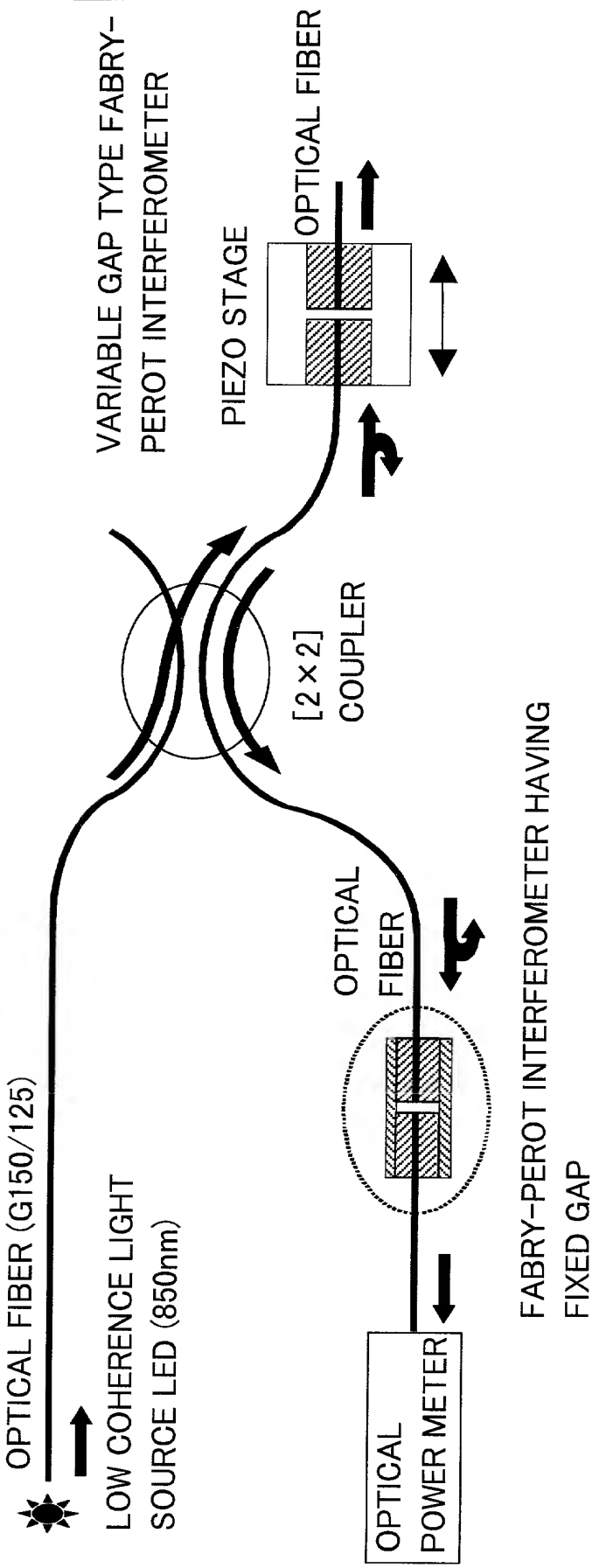


FIG. 35A PRIOR ART

MEASURING SYSTEM WITHOUT FIXED GAP TYPE FABRY-PEROT INTERFEROMETER

FIXED GAP TYPE FABRY-PEROT INTERFEROMETER (SENSOR)〈NONE〉

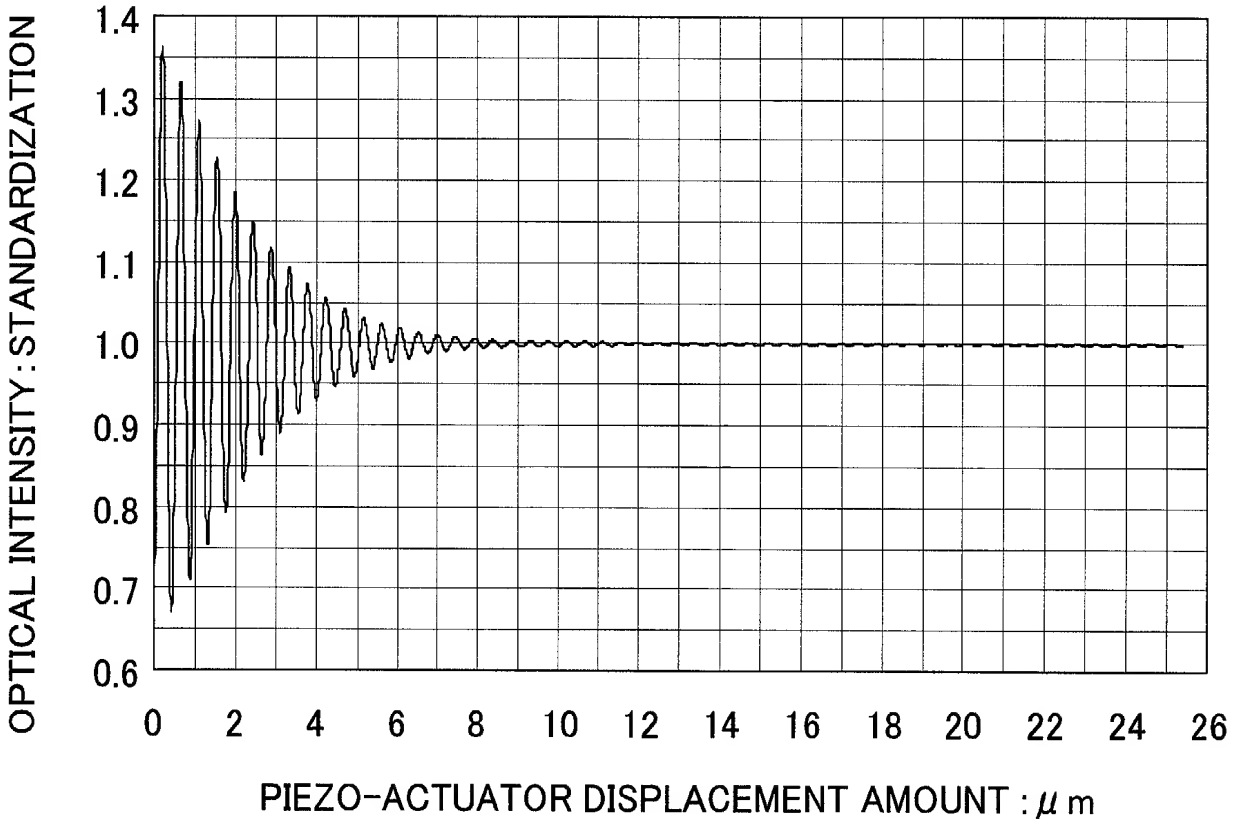


FIG. 35B PRIOR ART

MEASURING SYSTEM WITH FIXED GAP FABRY-PEROT INTERFEROMETER

FIXED GAP TYPE FABRY-PEROT INTERFEROMETER (SENSOR)〈INSTALLED〉

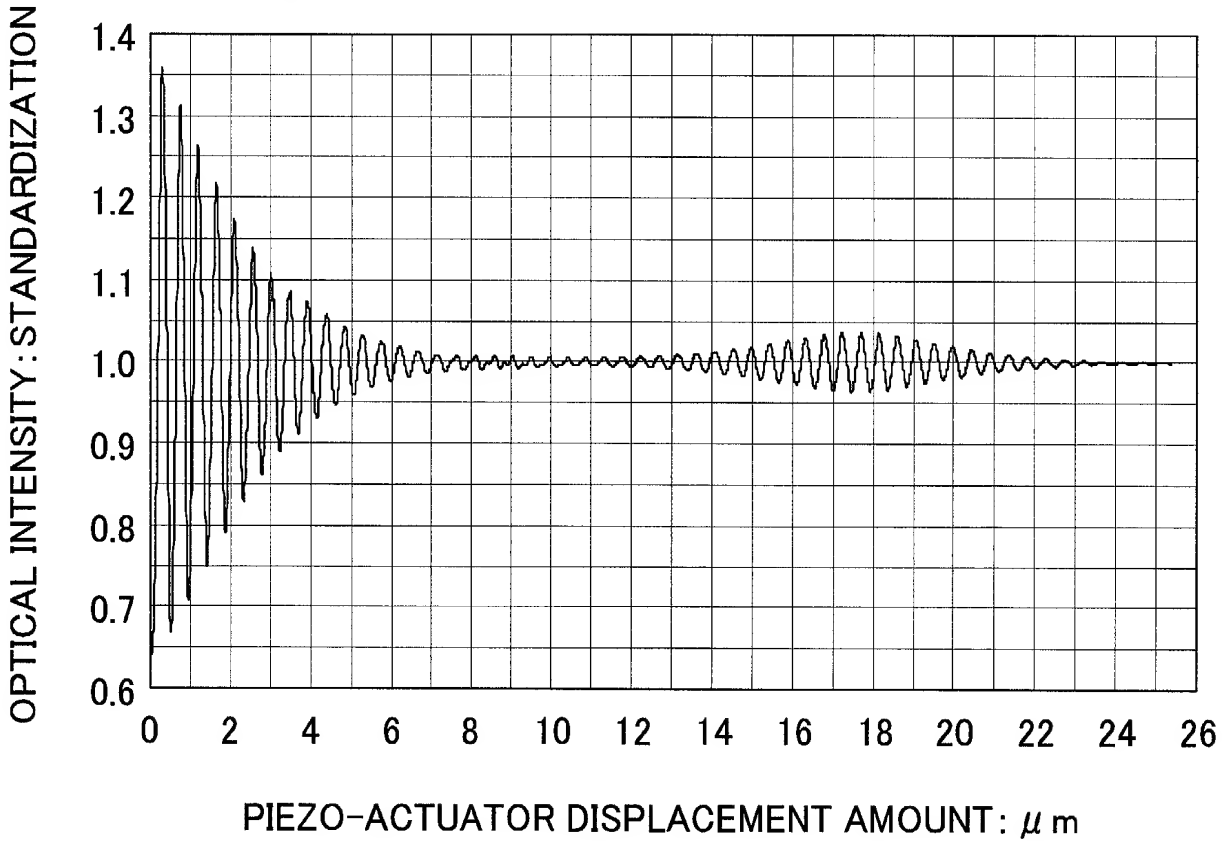


FIG. 36A

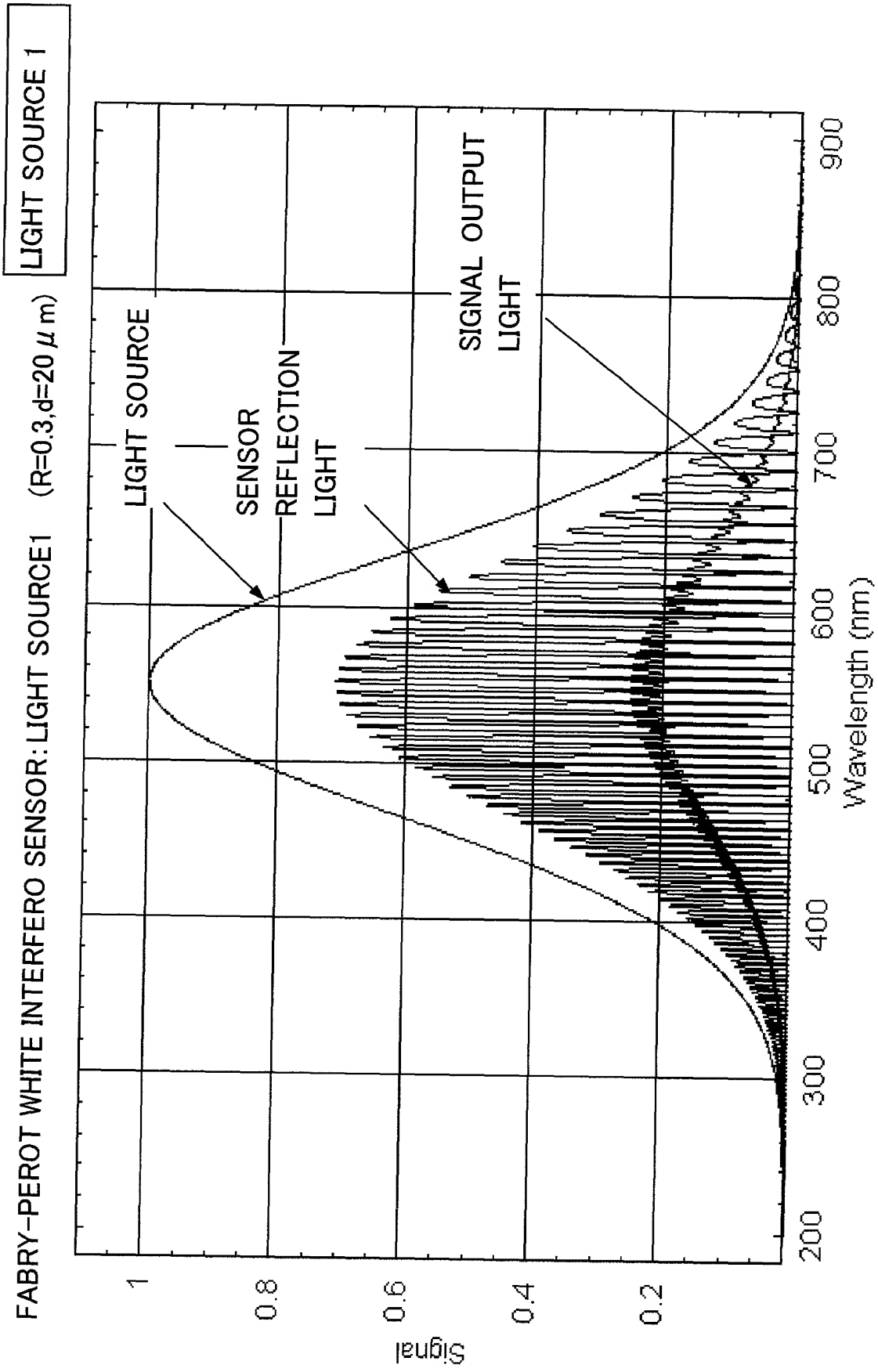

FABRY-PEROT WHITE INTERFERO SENSOR: LIGHT SOURCE1 (R=0.3,d=20 μm)
LIGHT SOURCE 1
LIGHT SOURCE
SENSOR REFLECTION LIGHT
SIGNAL OUTPUT LIGHT
Signal
1
0.8
0.6
0.4
0.2
200
300
400
500
600
700
800
900
Wavelength (nm)

FIG. 36B

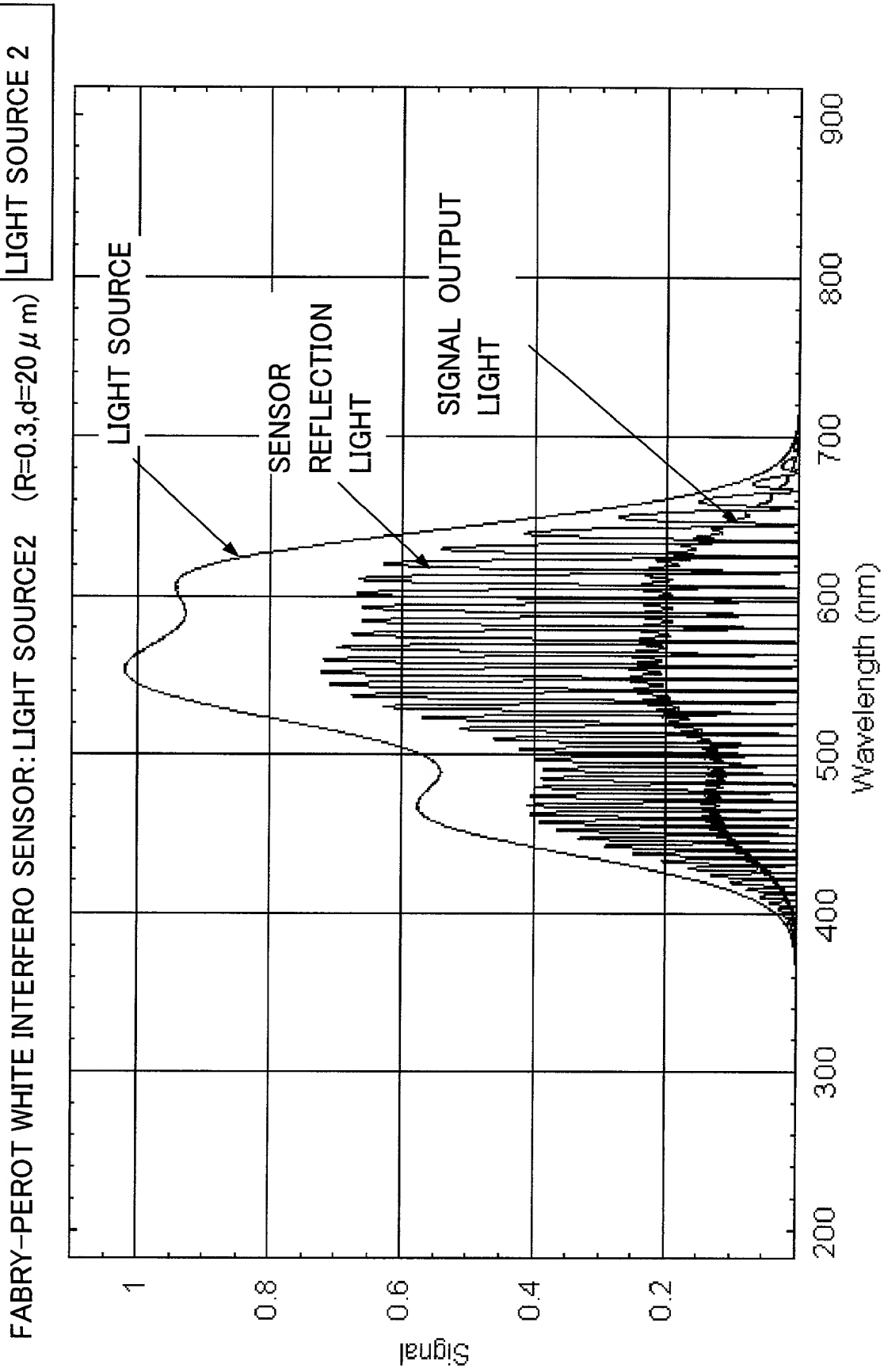

FABRY-PEROT WHITE INTERFERO SENSOR: LIGHT SOURCE2 (R=0.3,d=20 μ m)
LIGHT SOURCE 2
LIGHT SOURCE
SENSOR REFLECTION LIGHT
SIGNAL OUTPUT LIGHT
Signal
1
0.8
0.6
0.4
0.2
200
300
400
500
600
700
800
900
Wavelength (nm)

FIG. 36C

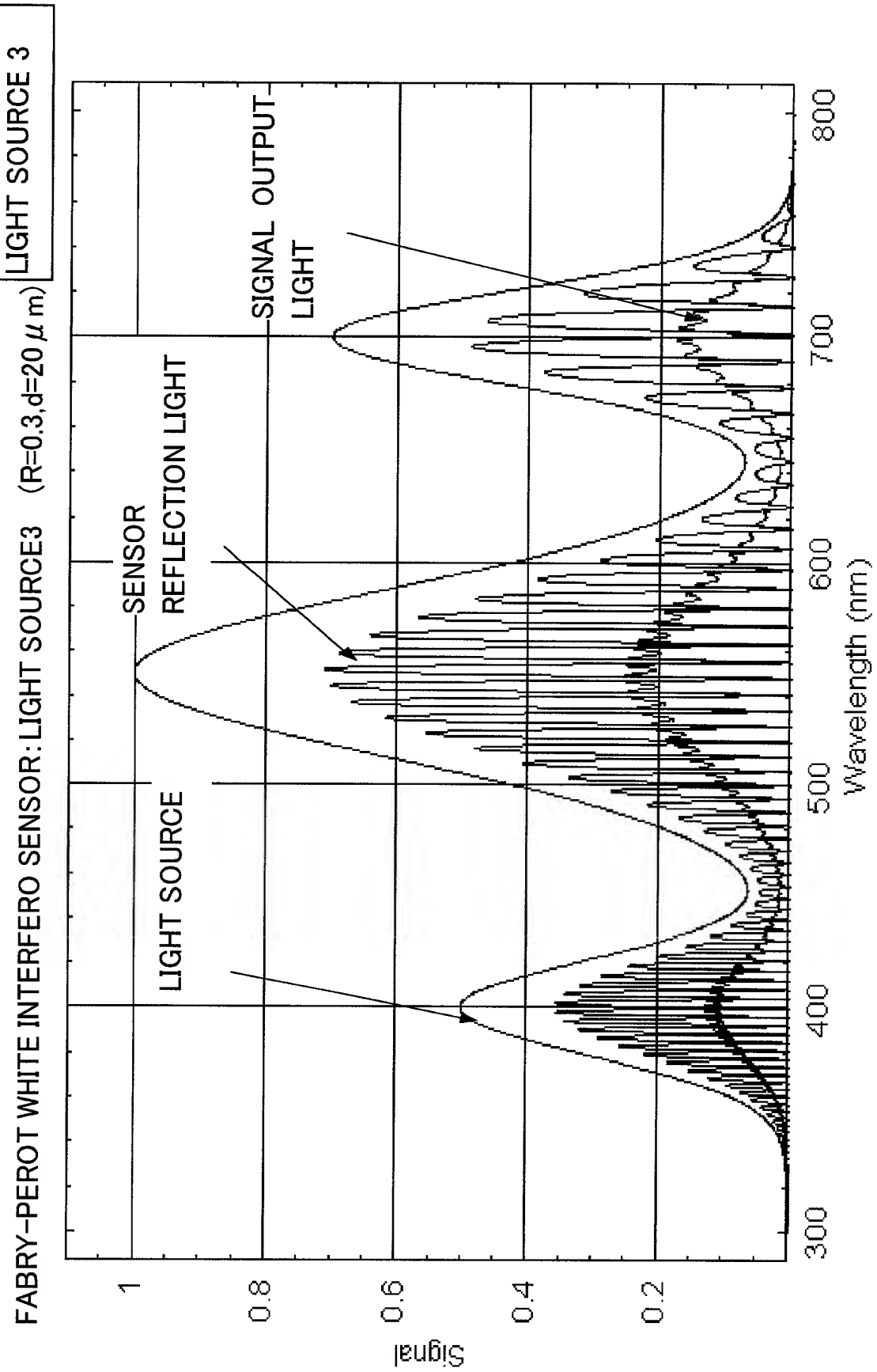

FABRY-PEROT WHITE INTERFERO SENSOR: LIGHT SOURCE3 (R=0.3, d=20 μm)
LIGHT SOURCE 3
SIGNAL OUTPUT LIGHT
SENSOR REFLECTION LIGHT
LIGHT SOURCE
Signal
1
0.8
0.6
0.4
0.2
300
400
500
600
700
800
Wavelength (nm)

FIG. 36D

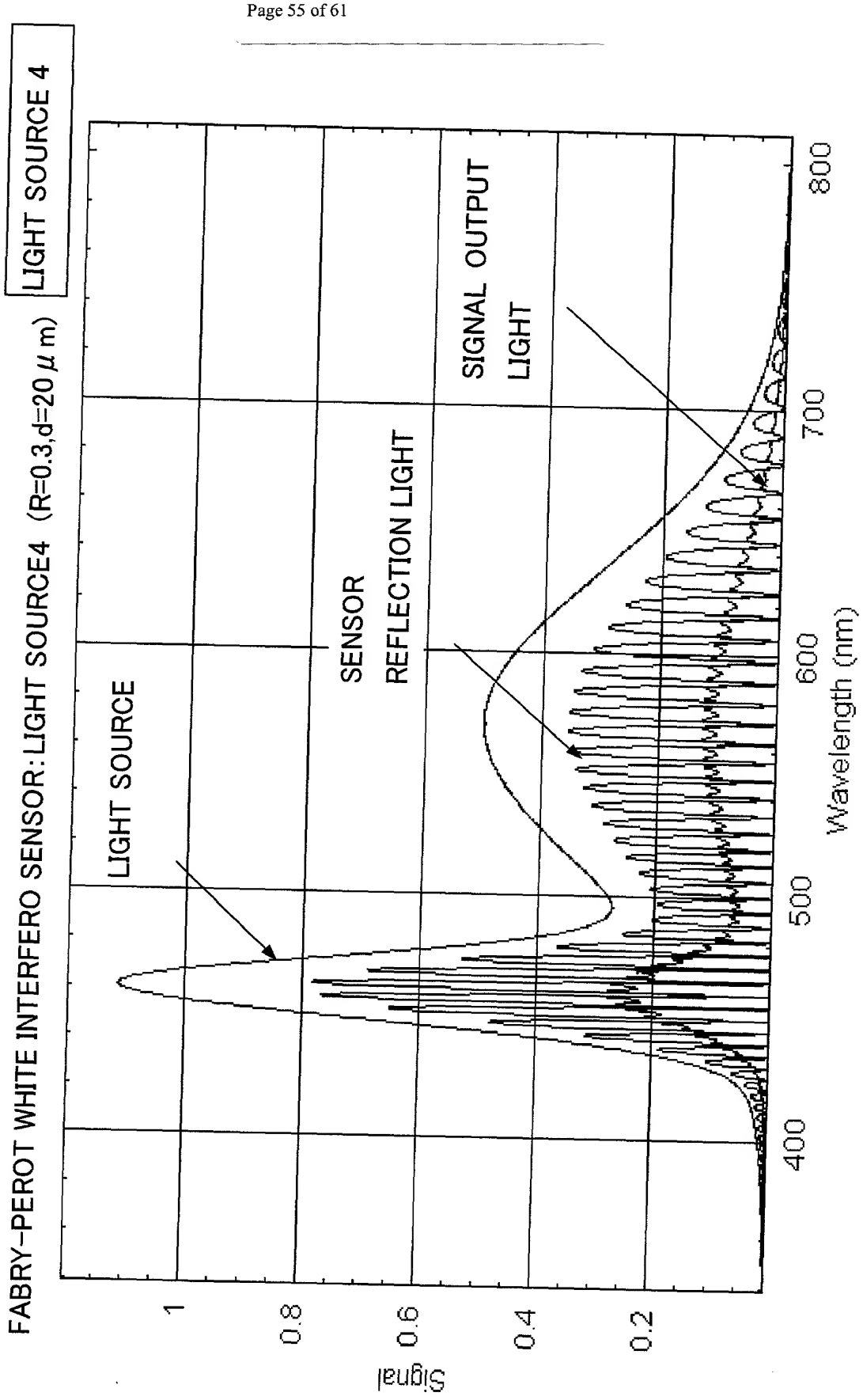

FABRY-PEROT WHITE INTERFERO SENSOR: LIGHT SOURCE4 (R=0.3,d=20 μm)
LIGHT SOURCE 4
LIGHT SOURCE
SENSOR REFLECTION LIGHT
SIGNAL OUTPUT LIGHT
Signal
1
0.8
0.6
0.4
0.2
400
500
600
700
800
Wavelength (nm)

FIG. 37

OUTPUT SIGNAL COMPARISON SIMULATION WITH LIGHT SOURCE HAVING FOUR DIFFERENT SPECTRUM DISTRIBUTIONS

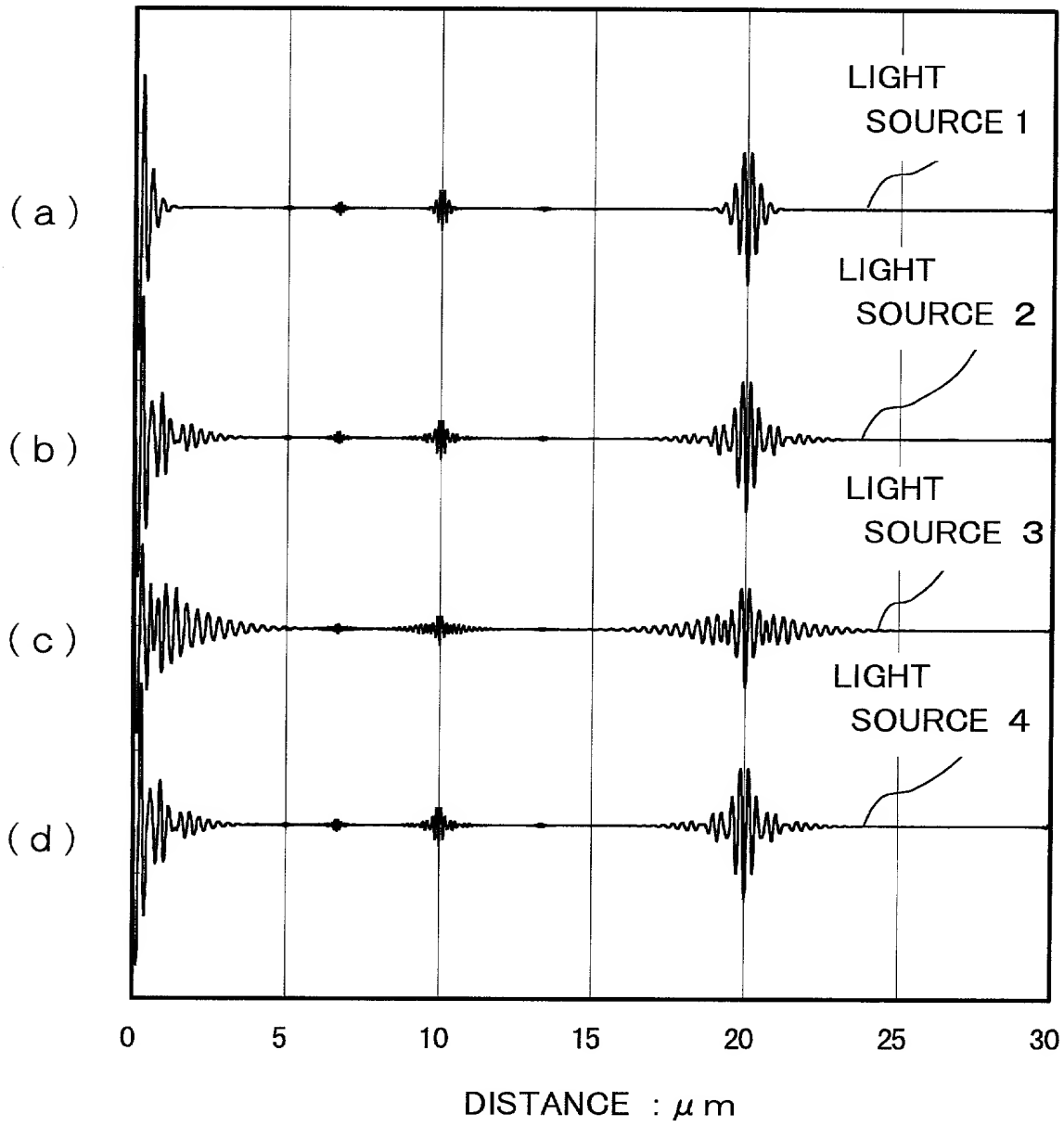


FIG. 38

OUTPUT SIGNAL COMPARISON SIMULATION WITH LIGHT SOURCE HAVING FOUR DIFFERENT SPECTRUM DISTRIBUTIONS

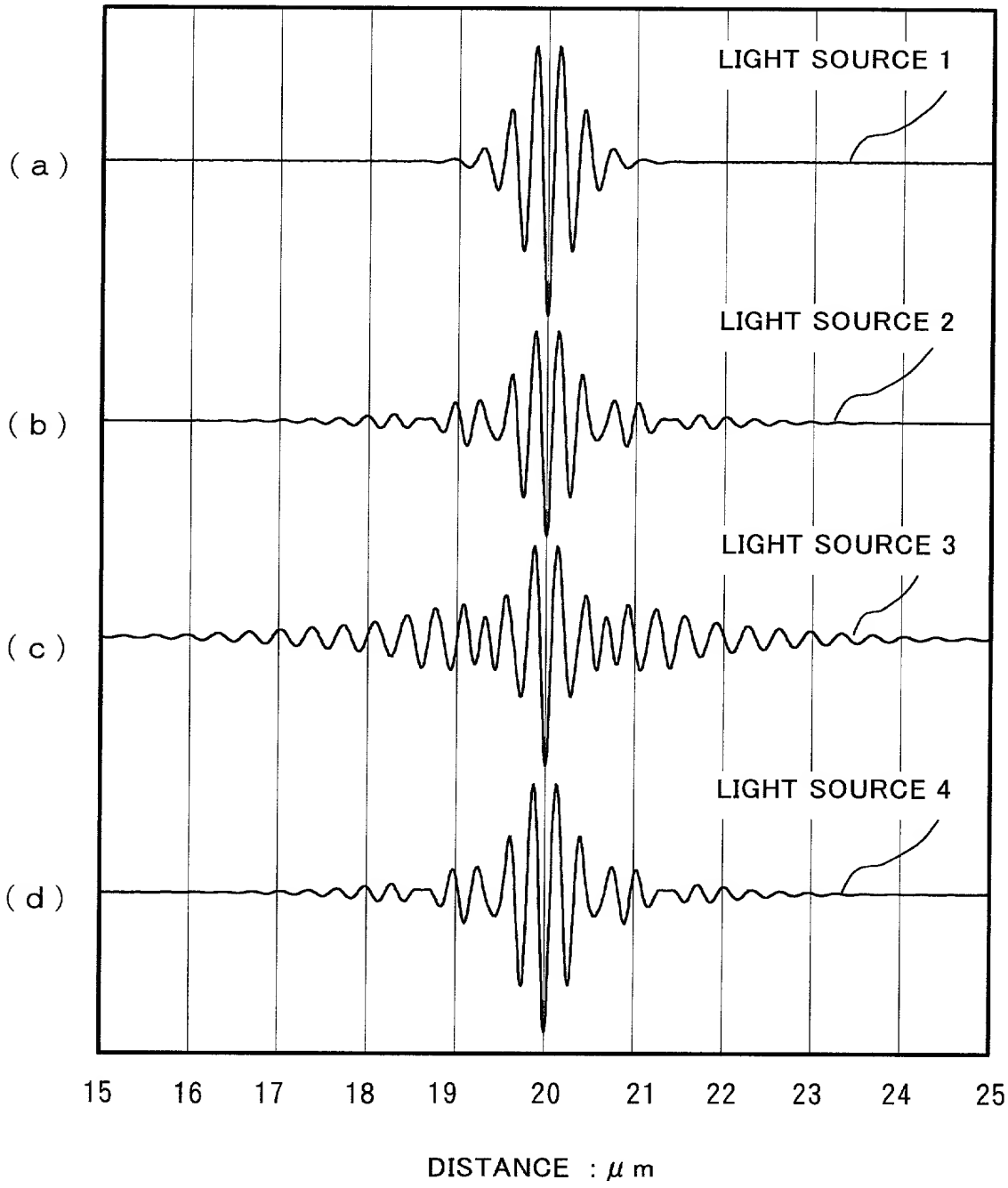


FIG. 39A

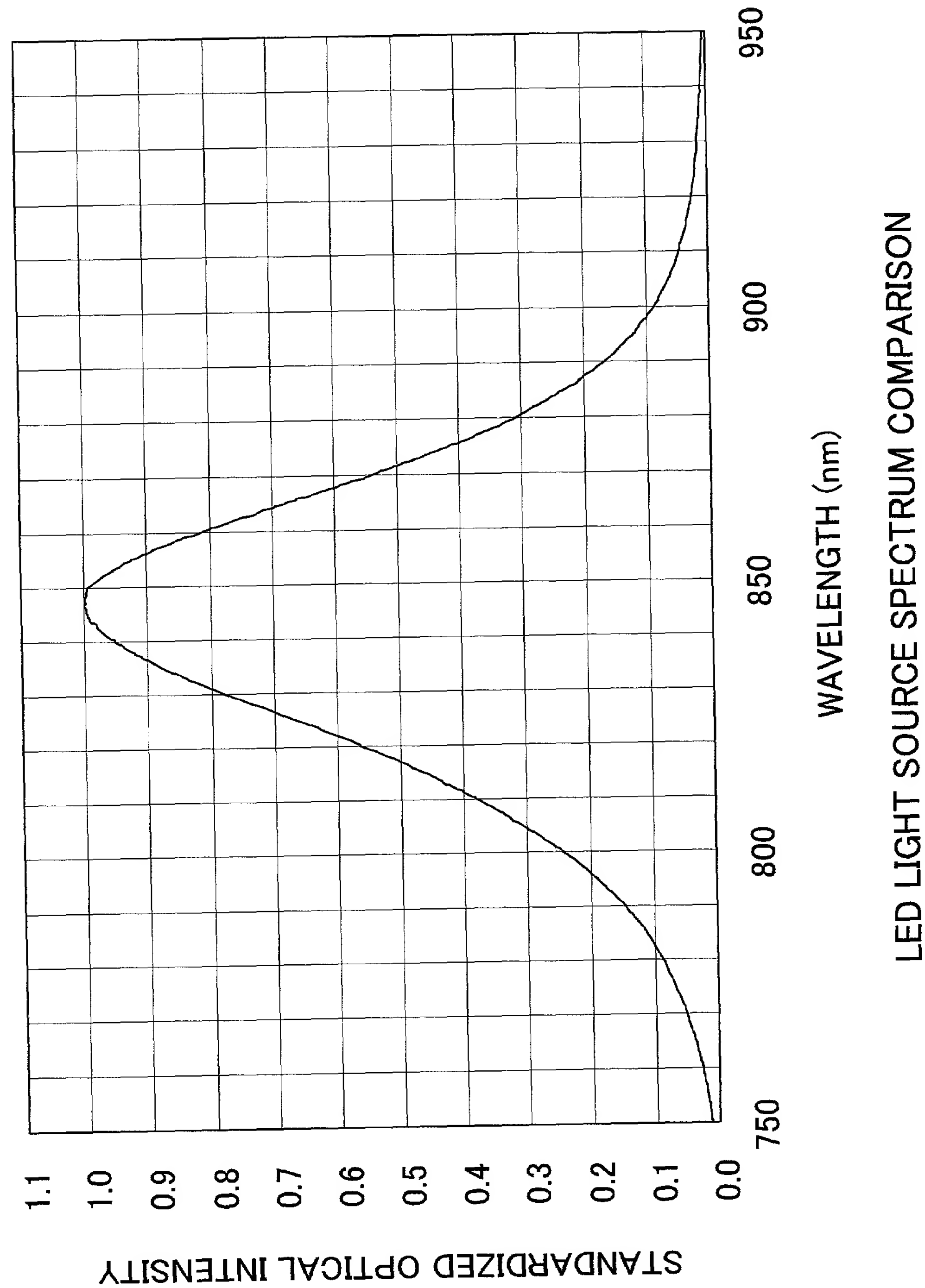

STANDARDIZED OPTICAL INTENSITY
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
750
800
850
900
950
WAVELENGTH (nm)
LED LIGHT SOURCE SPECTRUM COMPARISON

FIG. 39B

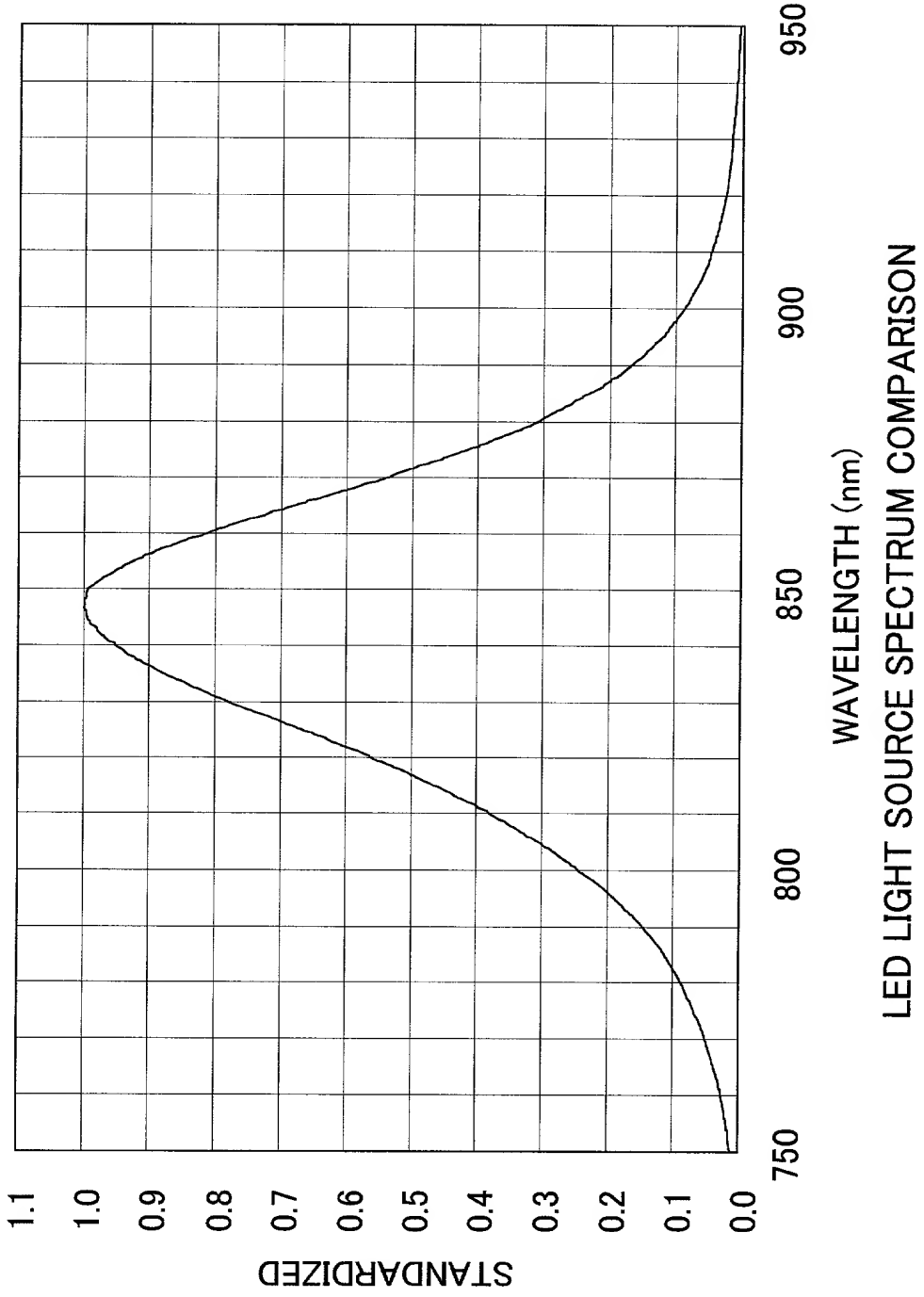

LED LIGHT SOURCE SPECTRUM COMPARISON
WAVELENGTH (nm)
750
800
850
900
950
STANDARDIZED
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1

FIG. 40A

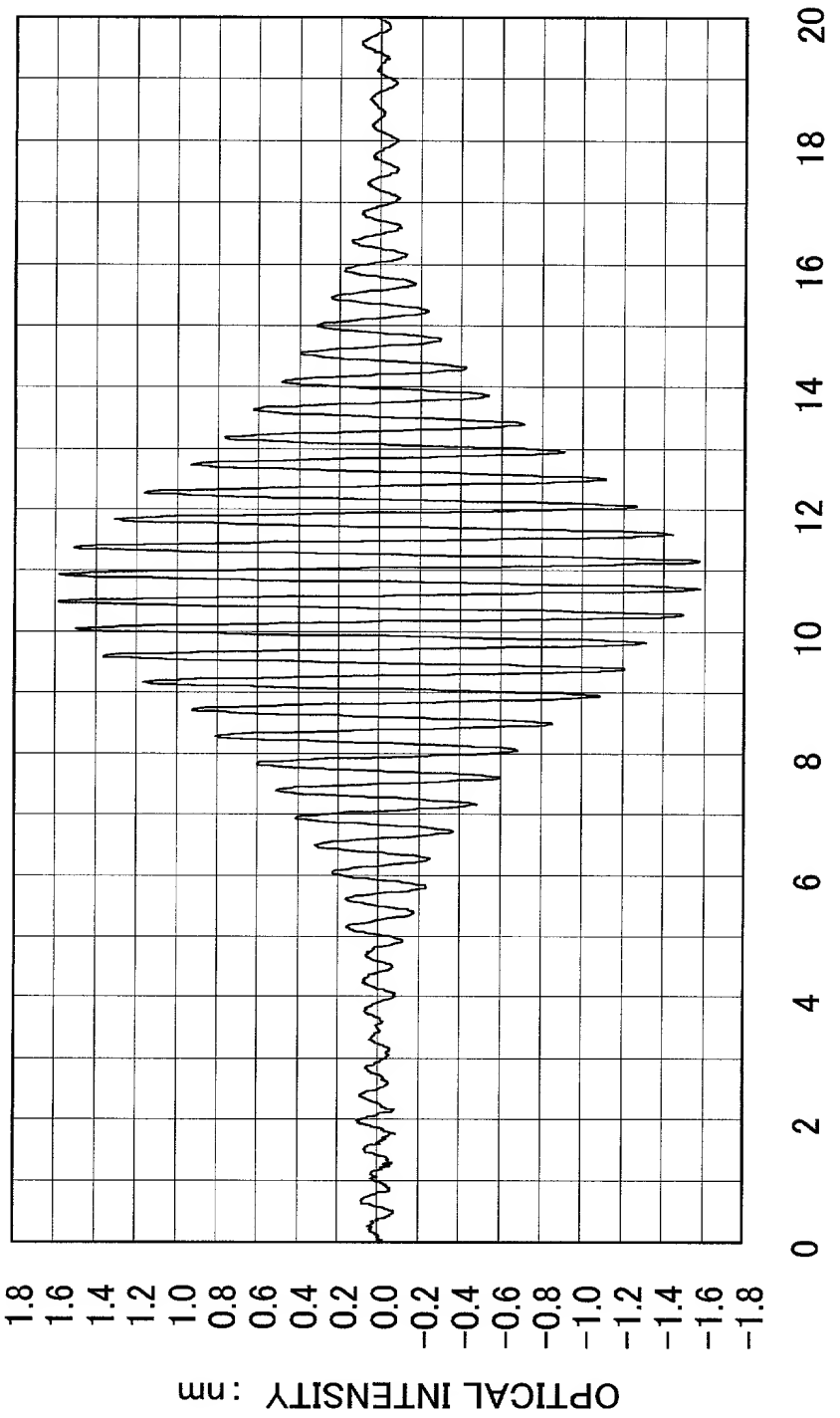
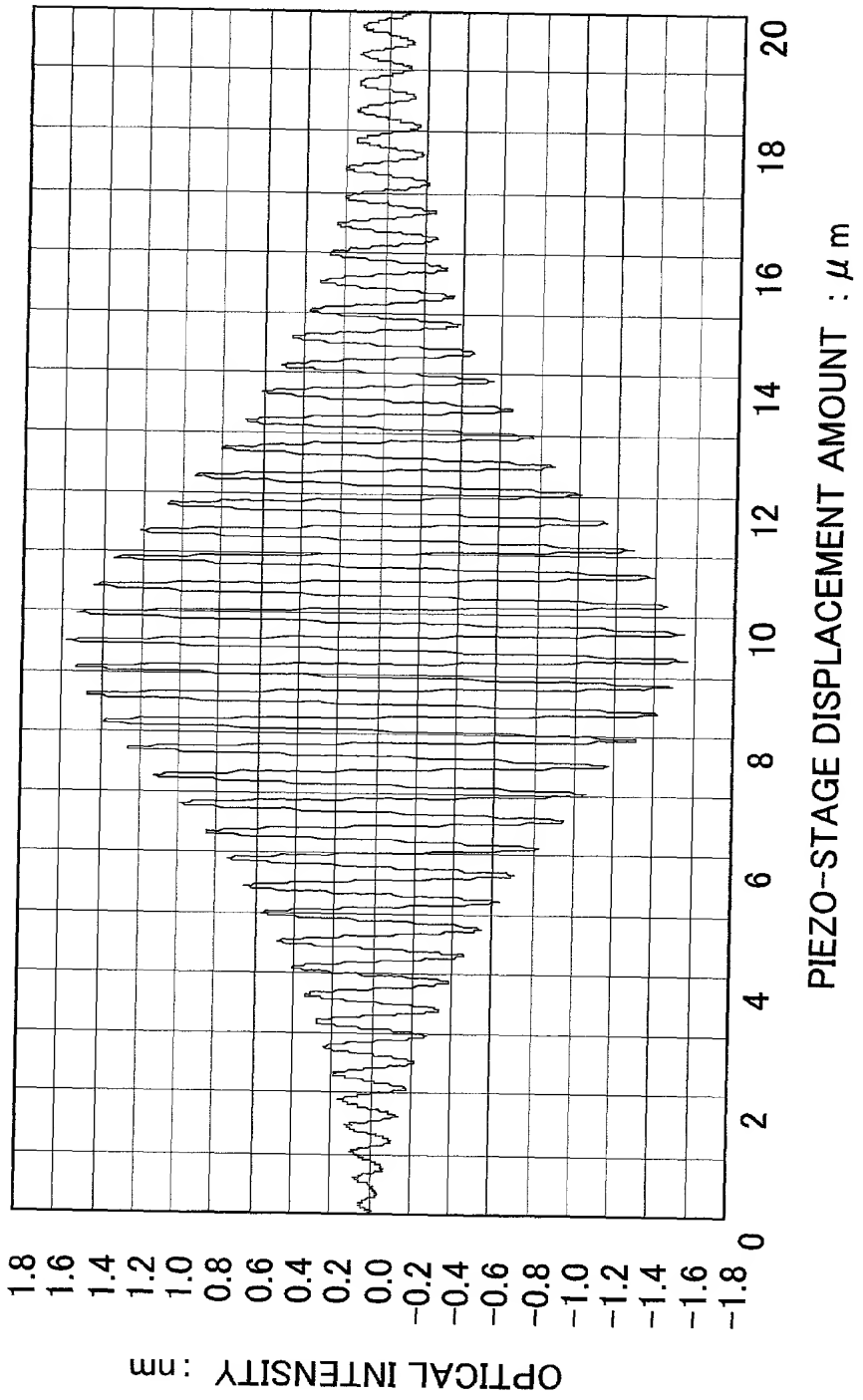

OPTICAL INTENSITY : nm
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
−1.4
−1.6
−1.8
0
2
4
6
8
10
12
14
16
18
20
PIEZO-STAGE DISPLACEMENT AMOUNT : μm
LED LIGHT SOURCE : OPTICAL CROSS-CORRELATION SIGNAL COMPARISON

FIG. 40B



LED LIGHT SOURCE : OPTICAL CROSS-CORRELATION SIGNAL COMPARISON